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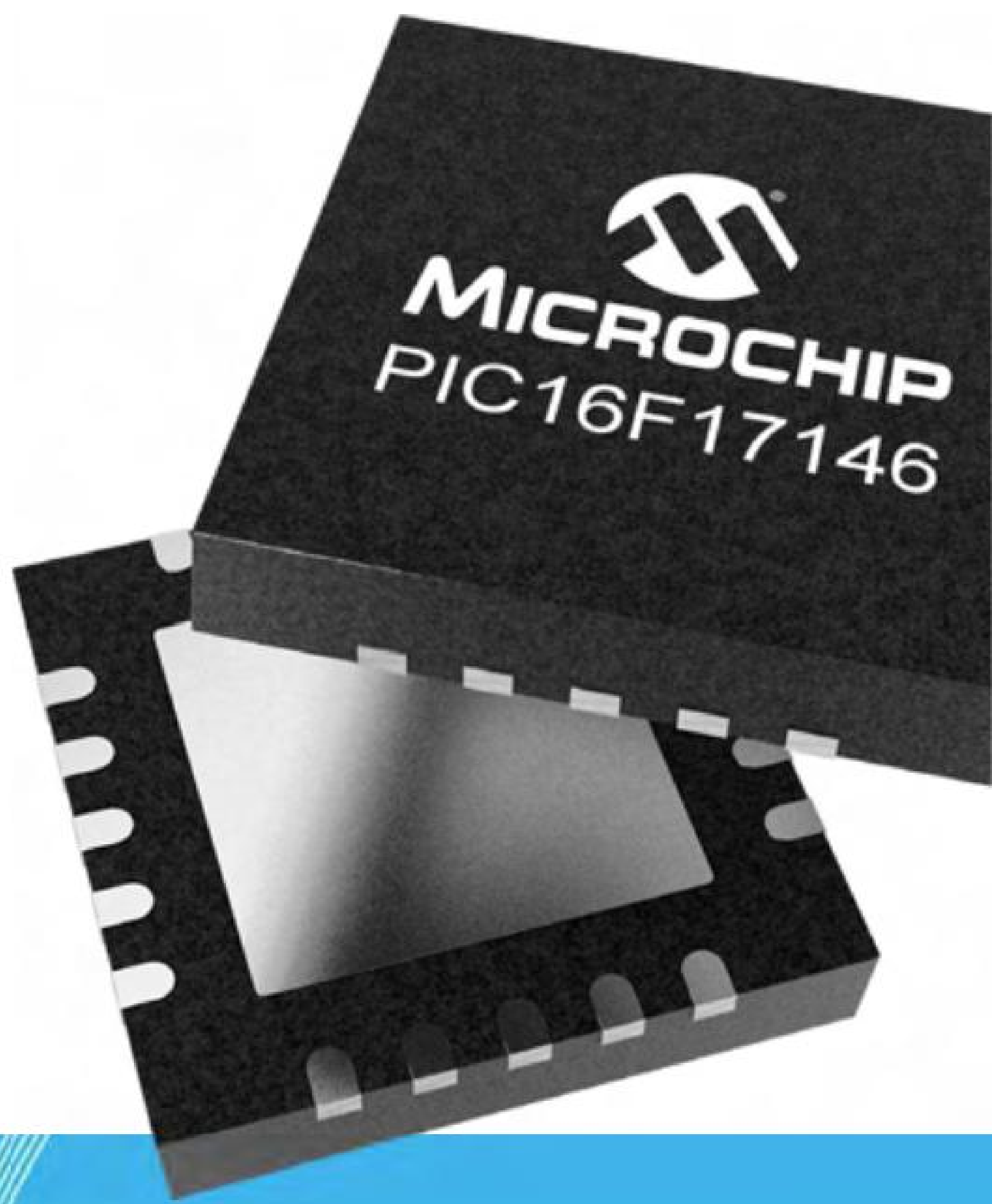

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Practical
Electronics

Volume 52. No. 11
November 2023
ISSN 2632 573X

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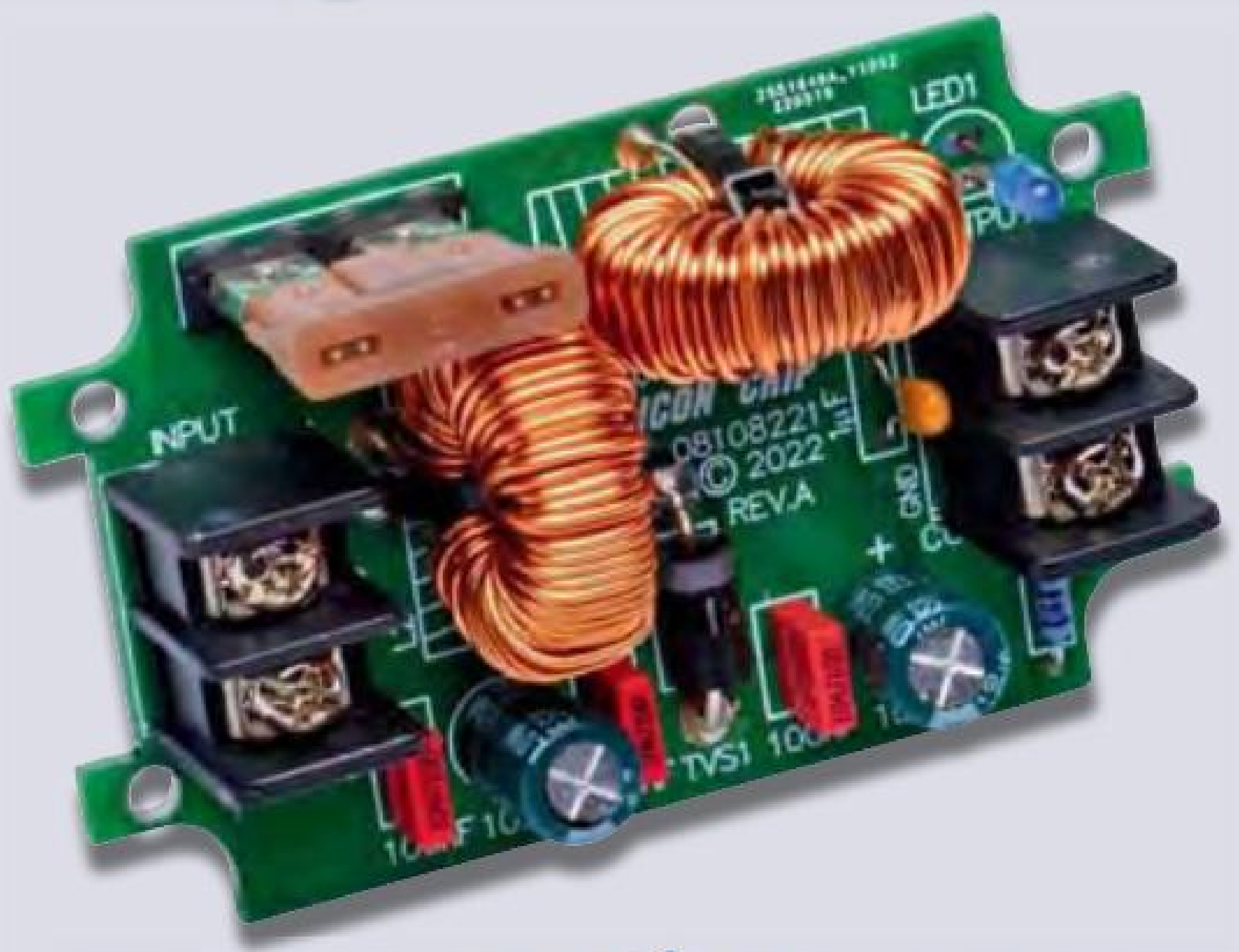

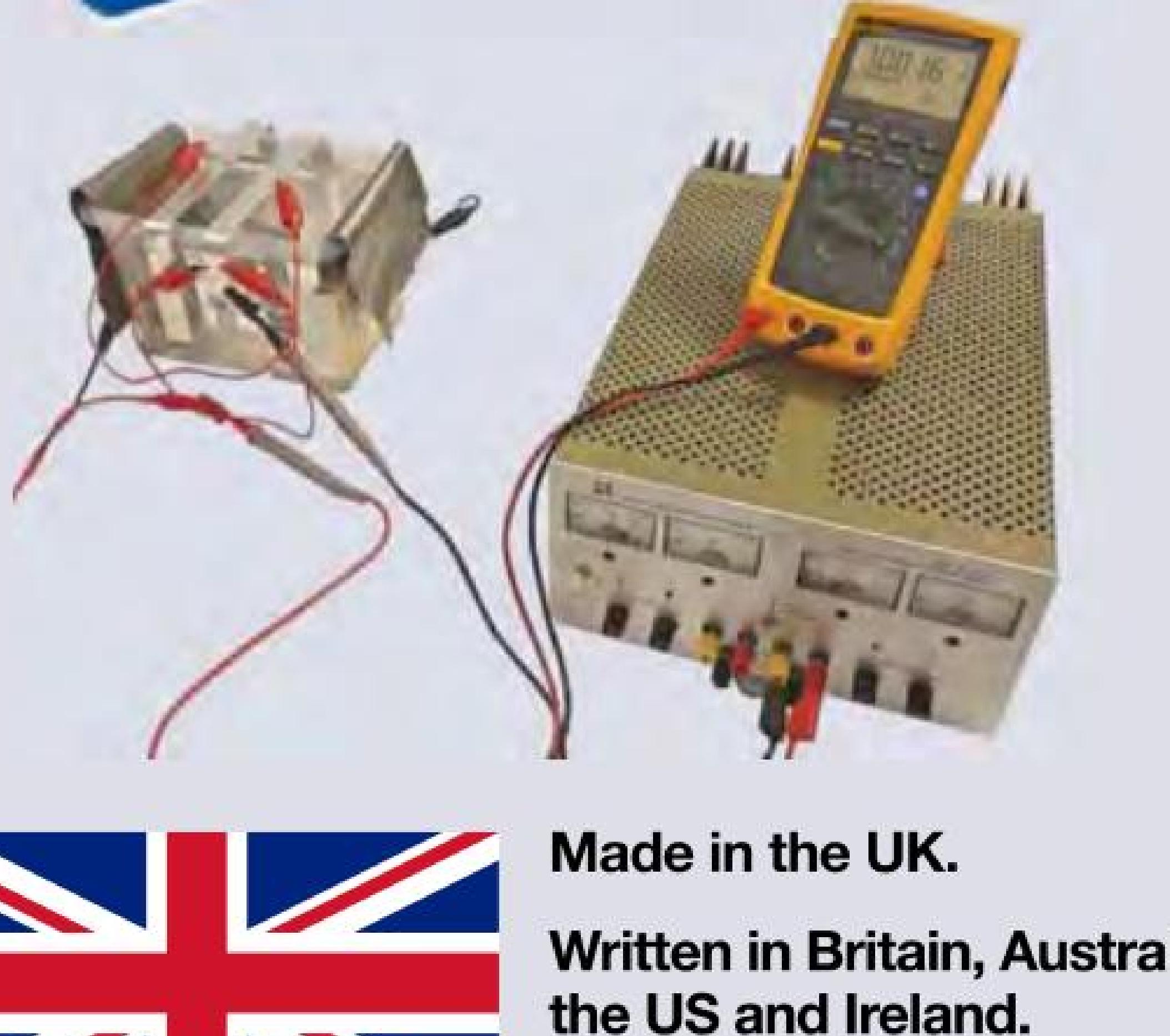

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Made in the UK.

Written in Britain, Australia, the US and Ireland.

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WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

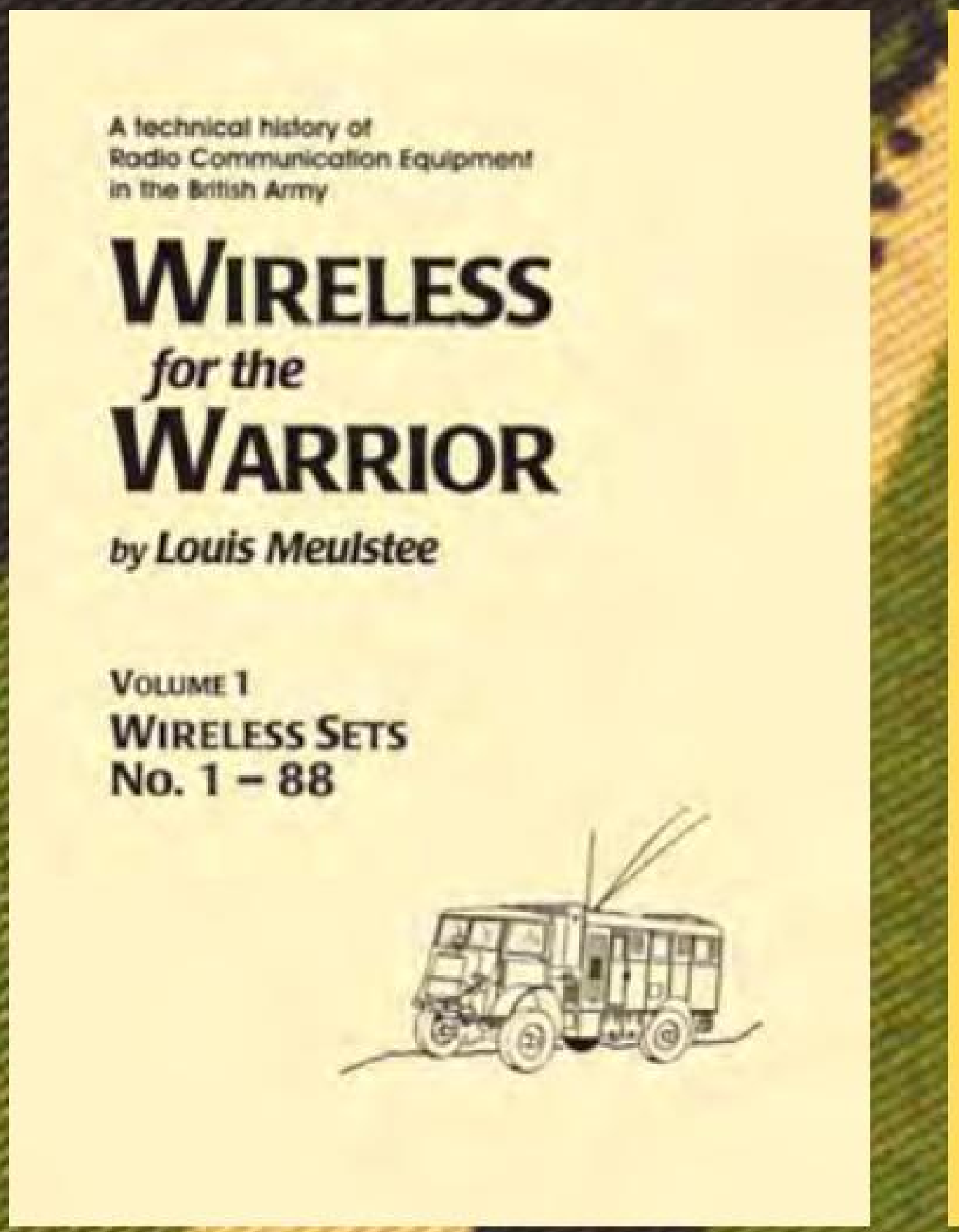
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

***Volume 1* and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.**

***Volume 3* covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.**

***Volume 4* covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.**



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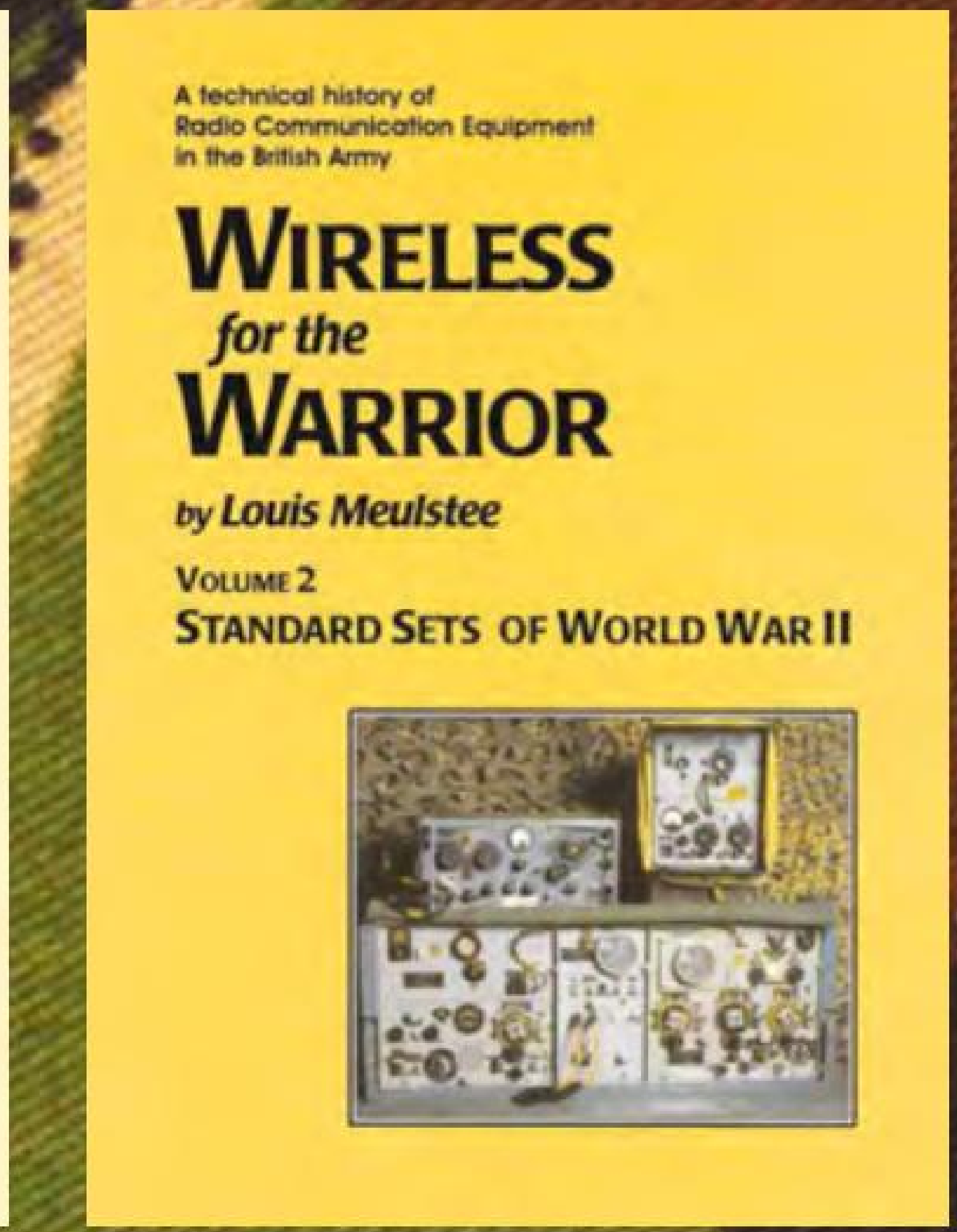

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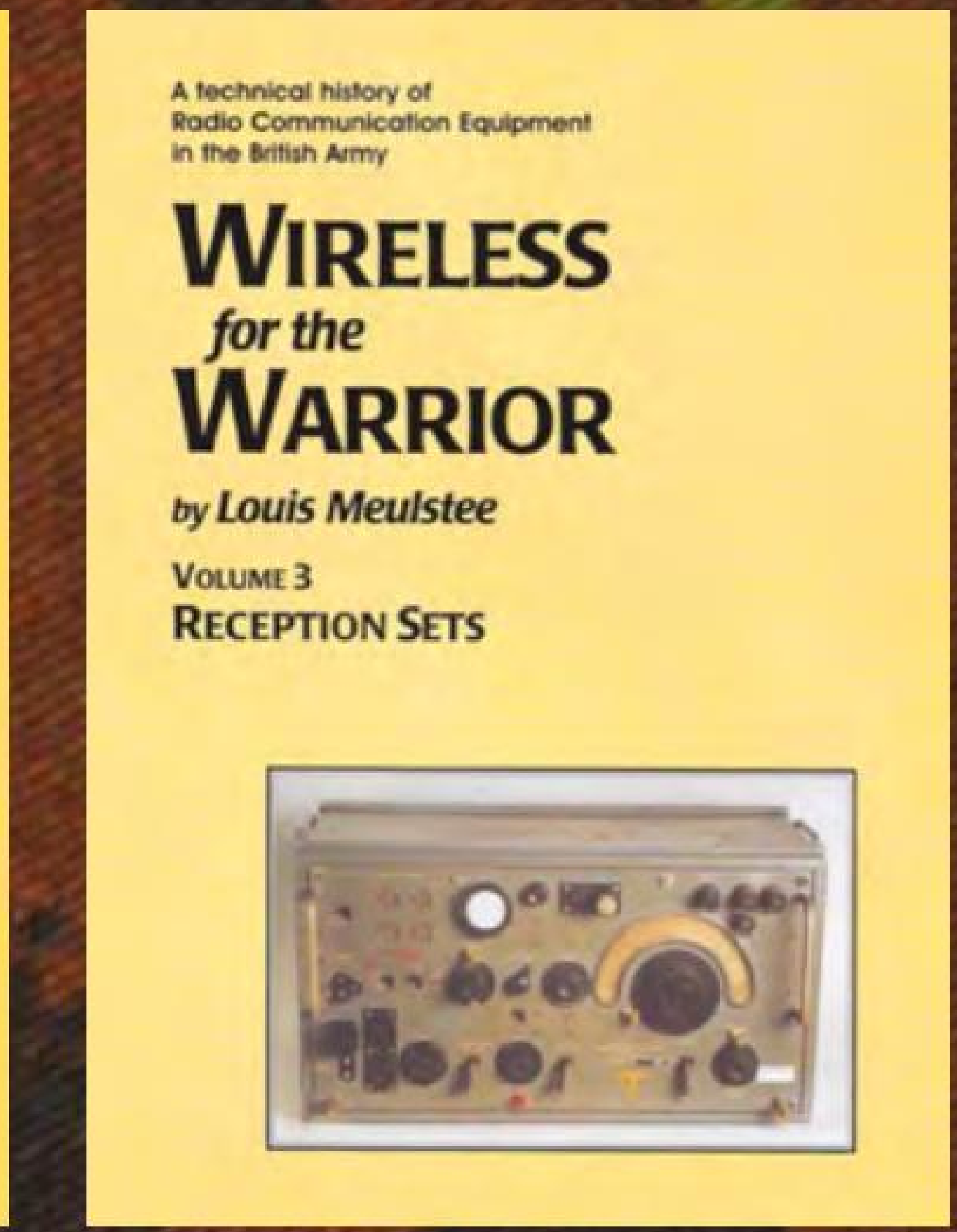

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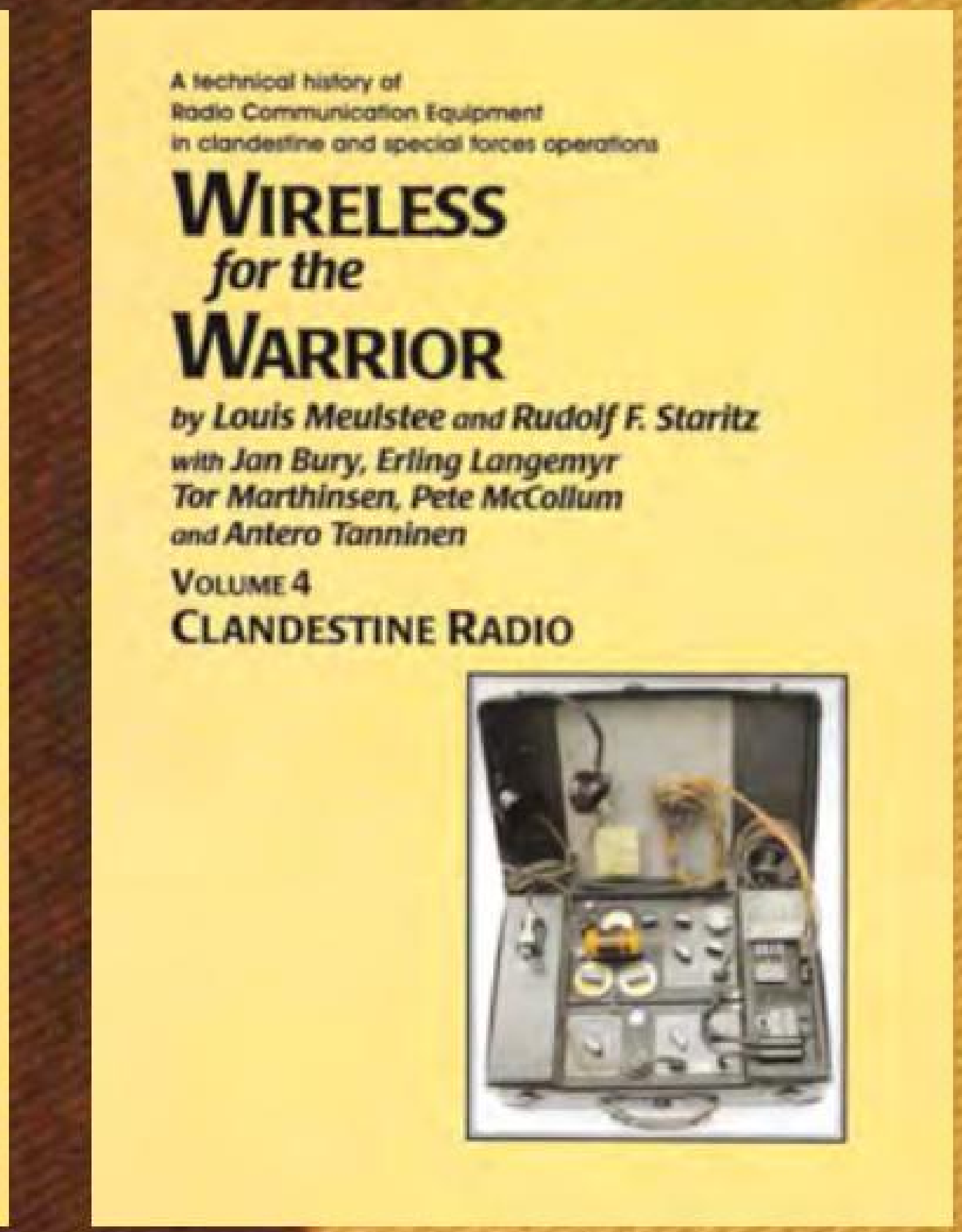

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in clandestine and special forces operations
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Mid G
High B
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High
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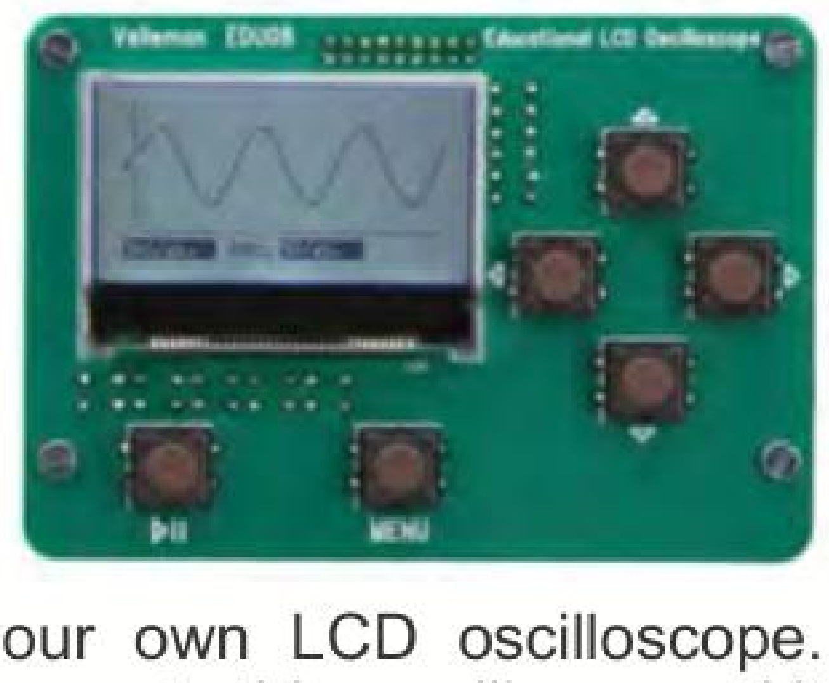

Build your own LCD oscilloscope with this exciting new kit. Learn how to read signals. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope kit has a lot of features found on expensive units like signal markers, frequency, dB, true RMS readouts and more. A powerful auto-setup function will get you going in a flash!
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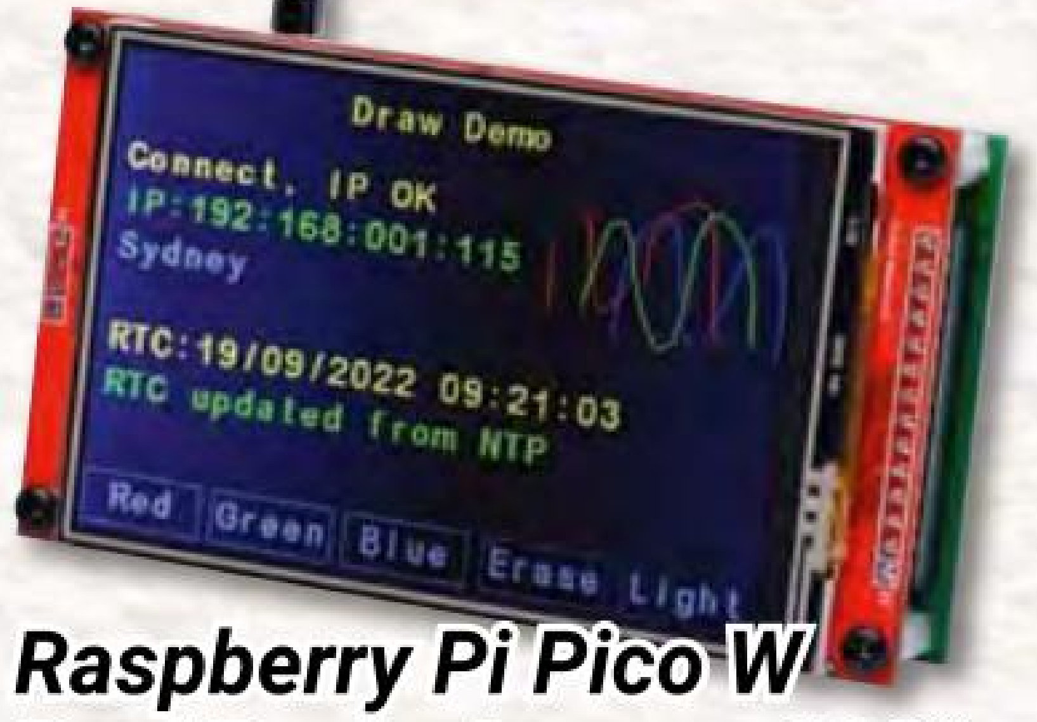
Draw Demo
Connect, IP OK
IP:192:168:001:115
Sydney
RTC:19/09/2022 09:21:03
RTC updated from NTP
Red
Green
Blue
Erase
Light

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All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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Upping your electronics housing game

You've chosen or designed your project, sourced the components, populated the PCB, tested the circuit and… it works. Congratulations, but what now? Well, you need to 'stick it in a box'. That's the basic plan, but housing electronic circuits is not a trivial undertaking.

A housing needs to protect your circuit – and, if it's a mains-powered project – the user(s). It also needs to support and arrange all the connections, switches, pushbuttons, pots and displays that accompany the circuit. Last, but not least, after all the effort of design, assembly, testing and troubleshooting, it really should look the part. You want to be proud of the result, and ensure it is durable.

Inevitably, this requires quite a lot of non-electronic skills: simple metalwork / 'plasticwork', such as drilling, sawing, filing and so on. At this stage it won't have escaped your notice that good-looking, well-made enclosures are not cheap. In fact, for simpler projects you often spend as much, if not more, on the box than on the circuit itself.

Recycle old housings

Often, you have two choices – buy new, or recycle. The latter is attractive but offers up one major problem. The front and back sections are often aluminium plates, which are – of course – already full of holes for the original circuit, along with legends describing their operation. The trick here is to buy a cheap, possibly very cheap dead unit and remove everything – including the front and back panels. Next, get some thick aluminium sheets cut to size to match the old panels. Now you can get to work, but plain aluminium can look a little tired and predictable, plus it is very soft, easily marred and any polish you apply will quickly fade as its surface corrodes in the atmosphere.

What you need is a way of toughening up aluminium and giving it your own special 'look'. Here's where anodising steps in – it's an electrochemical process that dyes, protects and strengthens the surface of aluminium. 'That's great, but how do I do it?' I hear you cry. Well, in this month's *PE* we will explain the method.

This is not the kind of technique we will run regularly in *PE* – after all, this is an electronics magazine. However, I feel sure many readers will enjoy using this process to give their housings a smarter, more original look.

Be safe!

Just one thing – anodising does involve some unpleasant chemicals. Always work safely and make sure you understand the hazards. Inexperienced, especially younger, readers must seek supervision!

Matt Pulzer
Publisher

Where's my pneumatic car?

Techno Talk

Max the Magnificent

Electric vehicles are a great idea, but the elements forming their batteries involve intensive and polluting mining operations and 70% of the electricity used to charge these batteries comes from nonrenewable sources, especially fossil fuels. Could pneumatic cars running on compressed air provide the answer?

If you look at a map of the world, it's easy to visualise the various continents as being part of a gigantic jigsaw puzzle. A big clue is that – in addition to their mirror-image shapes – the geologies at the edges of continents like the east coast of south America and the west coast of Africa match up.

The idea of continental drift was first espoused in 1912 by the German climatologist, geologist, geophysicist, and meteorologist, Alfred Wegener (I have no idea what he did in his spare time). However, it wasn't until technology was brought to bear that the underlying mechanisms began to be properly understood.

First, we discovered that the Earth's magnetic field periodically reverses. Many rocks contain iron-bearing minerals that can act like tiny magnets. When these rocks are heated and cooled, these tiny magnets become aligned to the current orientation of the Earth's magnetic field. According to the United States Geological Survey, these reversals can occur as often as every 10 thousand years or as infrequently as every 50 million years (the last reversal was about 780,000 years ago).

Second, during the late 1950s and early 1960s, the magnetic fields associated with rock samples retrieved from the floor of the Atlantic Ocean reflected how new crust is forming along the underwater Mid-Atlantic-Ridge, thereby pushing South America and Africa apart.

The amazing thing to me is that the theory of plate tectonics (the mechanism underlying continental drift) did not experience wide acceptance by most scientists in geology until around 1967, which is ten years after I was born, for goodness' sake!

Fancy a stroll?

Bolstered by modern technology, scientists can tell us all sorts of interesting things. For example, we now know that during the last ice age about 18,000 years ago, what is now Manhattan in New York was covered by an ice sheet about 600m (2,000 feet) high.

So much of the world's water was trapped in ice at that time that sea levels fell by around 120m (400 feet). As a result, it was possible for people to stroll from Europe to Britain. Over time, things started to warm, the ice melted, sea levels rose, and Britain returned to being an island, which is just the way we like it (and quite possibly for our neighbours too!).

Got gas?

Rising and falling temperatures are all part of the natural cycle. Sometimes these changes are extreme, with the world being much colder and hotter than it is today. For example, scientists currently believe that the entire planet has sometimes been completely covered with snow and ice. At other times, the world has been like a sauna. For example, researchers at the National Oceanic and Atmospheric Administration (NOAA) now believe that the global average temperature toward the end of the Neoproterozoic Era (around 550 million years ago) may have risen as high as ~32°C (90°F).

The problem is that changes that would typically span hundreds of thousands of years are now transpiring in decades. Due to climate change, deserts are expanding, glaciers are retreating, permafrost is melting, sea levels are rising, heat waves and wildfires are becoming more common, and the world is experiencing more intense storms, droughts, and other weather extremes. Even worse, I don't have anything suitable to wear.

The primary cause of our current problems is the amount of greenhouse gases like carbon dioxide we are pumping into the atmosphere. And the primary source of carbon dioxide is burning fossil fuels like coal, oil and natural gas.

Got wind?

One way to at least begin to mitigate our current climate change woes is to use renewable energy sources like wind power. A recent report by the US Department of Energy (DoE) predicts that wind turbines will provide 20% of US electricity needs by 2030.

These things can be *huge*. Each of the blades used in a typical modern land-based wind turbine are around 50m (170 feet) long, while China's LZ Blades company currently holds the record with a wind turbine whose blades are 123m (404 feet) long!

Are electric cars the answer?

There are currently around 1.5 billion cars in the world. The vast majority burn gasoline or diesel, but the number of electric vehicles (EVs) is starting to rise. One's knee-jerk reaction might be to think that our problems would be solved if all cars were EVs but – sad to relate – that's not the case.

The first issue is the batteries. Current automotive battery technologies are based on lithium, nickel, manganese, cobalt and graphite, along with a bunch of rare earth elements, all of which involve intensive and polluting mining operations. And I'm not even considering the problems associated with recycling and disposal when these batteries go end-of-life.

The second issue is charging the little scamps. Renewable energy sources (sun, wind, hydro) currently account for only around 30% of global electricity generation. The rest comes from nuclear or – you guessed it – burning fossil fuels.

Where's my pneumatic car?

For the past 20 years, I've been hearing about a novel French automobile company called *Moteur Developement International* that's developing a pneumatic car that runs on compressed air.

Admittedly, the range would only be around 100 miles on a full 'charge,' but that would cover 99% of my personal needs. Using a small pump located inside the car, its tank could be recharged for only a few pennies by plugging it into a regular wall outlet. Also, electricity to run the pump could come from solar panels mounted on the roof.

Will this technology ever come to pass? I don't know. I'm starting to lose hope. What I do know is that if these ever do go into production, I'll be at the front of the queue!

Win a Microchip MPLAB PICkit 5

Practical Electronics is offering its readers the chance to win a Microchip MPLAB PICkit 5 (PG164150) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The MPLAB PICkit 5 in-circuit debugger/programmer is a powerful tool that provides quick prototyping and production-ready programming for all Microchip devices. This versatile device is equipped with a range of features that make it the perfect companion for your programming needs. With the MPLAB Programmer-to-Go (PTG) mobile app, you can connect to the tool from your smartphone via Bluetooth and select from one of multiple saved .ptg files on the installed SD card to program.

With PTG support and the ability to save multiple program images to the SD card, you can easily switch between different programming tasks or set a new default image. This feature-rich device reduces costs and offers features and performance at a fraction of the cost of comparable debuggers/programmers.

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A wide variety of interfaces are supported by the MPLAB PICkit 5, such as four-wire JTAG or Serial Wire Debug (SWD) with streaming UART Virtual Comm Port (VCP), and with the Debugger Adapter Board (AC102015) developers can use standard connectors for JTAG, SWD, ICSP, and AVR Protocols.

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Net Work

Alan Winstanley

This month's column has news of new energy-saving incentives for smart meter users, the ORA Funky Cat BEV finally launches, some of Logitech's mice are considered and there's more space program news.

As winter approaches, with another potential energy crunch looming, news recently leaked out in Britain that some consumers would again be offered cash to reduce their energy consumption during periods when the energy supply was under pressure. It's now four years ago that I wrote about the country's faltering smart-meter programme which, on the face of it, was being marketed as a benign scheme to help users monitor energy consumption and save money (*Net Work*, December 2019). Back then, I wrote that 'ultimately, [smart meters] will change the way we manage our power consumption – and pay for it – for ever.' I think the same still holds true today.

In Great Britain, the National Grid ESO (Electricity System Operator) is responsible for delivering electricity to British homes and businesses: they own the wires and pylons, while separate electricity suppliers buy electricity from the power generators and resell it to end-users, as the National Grid explains at: **www.nationalgrideso.com**

In Q1 23, the renewable sector's share of total generation reached 47.8%, setting a new record. A network of interconnectors also enables gas and electricity to be exported or imported between the UK and other countries, see: **https://bit.ly/pe-nov23-ofgem**

The National Grid ESO Electricity National Control Centre (ENCC) manages electricity supplies across the country. (Image: National Grid)

A recent summary on energy trends by the UK Department for Energy Security and Net Zero showed that the UK actually exported 41% more gas compared with a year ago, to help prop up mainland Europe's energy shortfall. Furthermore, the UK has the second largest Liquefied Natural Gas (LNG) regasification network in the whole of Europe, the department says, allowing the UK to support mainland Europe's efforts to reduce its dependence on Russian gas.

The transmission of electricity is managed at the National Grid ESO Electricity National Control Centre (ENCC). The huge problem we face is of course the lack of spare capacity, especially if a severe winter threatens. The idea behind Demand-Side Response (DSR) is to iron out the peaks and troughs by balancing the available

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energy with customer demand. Smart meters will enable demand for energy to be 'shaped' and, if necessary, consumers could be encouraged to turn down the lights at peak times by, for example, offering them cash rebates.

Limited trials were held early this year when the National Grid implemented its so-called Demand Flexibility Service (DFS) for the very first time, which gave modest rebates to some users who reduced their demand. A further 12 DFS tests will be held this winter, says the National Grid, starting in November 2023 through to March 2024. This will help to show whether the scheme is commercially viable, noting that participants with a smart meter need to sign up for DFS through their own supplier. (As more evidence of the direction of travel, there really is such a thing as the 2023 Net Zero 'Behaviour Change Campaign of the Year' and National Grid ESO's Demand Flexibility Service is shortlisted for an industry award.)

In theory, smart meter customers could also be switched to other tariffs or pricier pre-payment packages, or ultimately be disconnected altogether, all by remote control. Since a lot of raw data is already out there, it's not inconceivable that users could eventually be charged extra for using power on calm and cloudy winter days if wind and solar energy were in short supply, as another incentive to turn down the heating. Meanwhile, my own energy supplier, EDF, has tried contacting me more than 100 times by phone, text and mail to book a smart meter installation but I'm resisting for as long as I still have a choice.

Despite having a mixed reputation, many users are very happy with their smart meter and find them useful in managing their energy accounts, but there are numerous problems with In-Home Displays not working properly and the UK Citizen's Advice Bureau has now devoted a useful section to dealing with IHD problems, see: **https://tinyurl.com/28oso42x**

Trading places

To a layman, there may seem to be a lot of horse-trading going on somewhere if suppliers claim they offer 'green energy' or '100% renewable' energy to their customers. After all, Britain's electricity comes from various sources (power stations, solar, wind and so on) which all feed into the same National Grid. As far as end users are concerned, it's just electricity coming out of the wall socket, whether it's from a nuclear power station or a wind farm somewhere in the North Sea. So, if it's all the same stuff, how can we know if our 'green' electricity actually comes from renewables and not, say, from a nuclear power station in France instead?

Energy supplier E.ON is up front about this, stating that its renewables tariff is 'Electricity backed by 100% renewable sources, E.ON's renewable generation assets ... and the purchase of renewable electricity certificates. The electricity supplied to your home or business comes from the National Grid.'

The subject of electricity certificates is a complex paper exercise and it's managed through the voluntary adoption of what are called 'Energy Attribute Certificates' (EACs). Trying to unpick how they work makes for some heavy reading, but essentially it boils down to having a system of verifying and certifying the output from energy producers in terms of where the MWh units of energy actually come from. In effect, this electricity generation data is then 'booked' or totalled up and it then goes into a virtual melting pot. EACs are described as 'tradable digital certificates' that contain factual details of how every MWh of energy was generated. They can then be 'claimed' or traded, regardless of where the underlying commodity (electricity in this case) originally came from.

Suppliers can dip into this finite pot to buy or trade certificates, either as one-offs or under contract. Using this 'book and claim' method, the industry gains a tight understanding of how much energy is produced, and of what type, and rigid controls help ensure that electricity sources can't therefore be 'over-sold'. The same system of certificates extends to carbon capture and low-carbon hydrogen distribution. I can't say how rigorous or robust the scheme actually is in practice, but in-depth details of how the system of EACs operates are provided by the non-profit International REC Standard body at: **www.irecstandard.org**

A cool and Funky Cat

Adverts have started appearing online for the ORA Funky Cat, a cute-looking battery electric vehicle (BEV) produced in China by Great Wall Motor (first described in *Net Work*, January 2022). It's known locally as the *Haomao* (Mandarin for 'Good Cat'). The BEV scored an impressive 5 star rating in Euro NCAPs safety tests and its makers hope that its attractive retro styling and equipment levels will win over many buyers. Prices now start at £32,000 which, like most BEVs, is a very tall order for many hard-stretched drivers today, but finance and PCP are also offered. You can take a look at: **https://gwmora.co.uk**

Car sales are 20% up on last year, driven mostly by fleet sales, as the sector emerges from the pandemic and problems with semiconductor shortages finally recede. While the sanguine motoring press claims that BEV sales are up by 72.3%, that's only comparing August 2023 (17,200 units) sales with the same time last year (10,000). A quick glance at the latest SMMT statistics shows that, year to date, just one in six cars (16.4%) sold were BEVs. Petrol cars remain the biggest sellers, with 41.6% of the market, leaving 42% for hybrids of all types, plus diesels, remembering that hybrid EVs still have engines in them!

The ORA will face fierce competition from a revitalised MG Cars with BYD (Build Your Dreams – see *Net Work*, May 2023) introducing soon its next EV, the well-regarded BYD Seal. China's SAIC, the owners of MG Cars, is contemplating building its first factory in Europe and also expects to launch an electric sports car – the MG Cyberster – next year, with a teaser shown on: **www.mgmotor.eu/model/cyberster**

ORA FUNKY CAT

The attractive-looking Ora Funky Cat has gone on sale in Britain starting at £32,000: it will face fierce competition from rival EV brands.

The 20-year old Logitech MX1000 is reckoned by the author to be one of the best full-size cordless mice ever made. Its microswitches, batteries and PTFE skids are repairable.

With stock levels rising and availability improving, used car prices have fallen in the last five consecutive months, says *Car Dealer* magazine, but traders are still being very picky about stocking electric vehicles. Meantime, TV screens continue to pump out adverts for space-age BEVs that it seems five out of six car buyers can't afford or don't want to purchase.

Totally IlLogitech

Last month, I mentioned how some of Logitech's early webcams utilised AI image-processing software that enabled the camera to 'follow' a moving subject. During the Covid lockdown, many staff chose (or were ordered) to work from home, which, along with semiconductor shortages, sent the price of webcams, laptops and gaming peripherals soaring. Supplies often dried up, and some readers might recall how I tried sourcing a Logitech C280 webcam for myself during the pandemic crisis. After I finally pinned one down, my triumph was short-lived as the highly prized (and over-priced) peripheral disappeared mysteriously while en route from Amazon in Italy.

Logitech clearly made the most of the lockdown period: accounts filed in the USA show how Logitech's gross profits more than doubled from $1.1bn in the year ended 31 March 2020 to $2.3bn in 2021, and net income before taxes more than tripled in the same period.

Since then, sales of all product ranges have fallen across the board, with Logitech reporting that webcam sales have declined by 44% and net income has plunged by 60%. Perhaps hard-stretched consumers are making do with what they've got in, or the latest products offer few benefits and aren't worth the investment in time and money. Logitech's Chair and CEO Bracken Darrell, the name credited with transforming Logitech's fortunes in the last decade, jumped ship in July to head up the clothing brand VF Corporation (The North Face, Timberland, Dickies).

From RAGS to riches

Many seasoned PC users will have used Logitech keyboards and mice at one time or other and, in my experience, one of the best computer mice ever made was the Logitech MX1000 Laser launched about 20 years ago. This cordless mouse had a meaty, ergonomic form factor that fitted one's (right) hand perfectly. Sought-after new old stock (NOS) models can fetch £200 ($250) or more on eBay today.

Instead of throwing cash at expensive replacements, I service or repair my MX1000 every few years. The grippy, rubberised finish eventually wears off or goes sticky, something easily cleaned off with isopropanol. Eventually, switch-bounce causes troublesome double-clicking, but the Omron microswitches are repairable with some careful de-soldering. Not that I obsess about it, but the battery and stick-on PTFE feet (skates or skids) can all be sourced from eBay or AliExpress and I'll sometimes buy tidy used examples for spares.

One of Logitech's legacies is their annoying habit of giving items a model number (M/N) as well as a user-friendly name, which makes searching for FAQs, tech support or drivers frustrating at times. My 'MX™1000 Laser Mouse', as they call it, is also known as an 'M-RAG97' but searching Logitech's website for either phrase returned no results.

Eventually, I scrolled through the 'Support for Individuals' section to find the elusive mouse and – more importantly – the legacy Setpoint driver software that's needed to get the best out of it. However, I still hit a brick wall as several web pages were 404, and no software was available anyway – one reason why it's a good idea to back up old drivers or keep old product CD ROMs. Despite all these setbacks, my mouse is working almost as well as the day it was bought, running perfectly on Windows 98 through to Windows 10.

Pointing left

Not that I'm against progress: a few months earlier, after checking out Logitech's latest mouse range for a Windows PC that was going abroad, I chose a Logitech Signature M650 L 'full size wireless mouse' which seemed the best mid-priced choice for larger (hence the 'L' suffix) hands. A version designed for left-handed users is also offered, named the 'M650 L LEFT'.

Logitech's Signature M650 L wireless mouse is described as a 'large size' mouse for large hands. It's also available as a left-handed version. USB 'Bolt' adapter also shown; the mouse can also use Bluetooth.

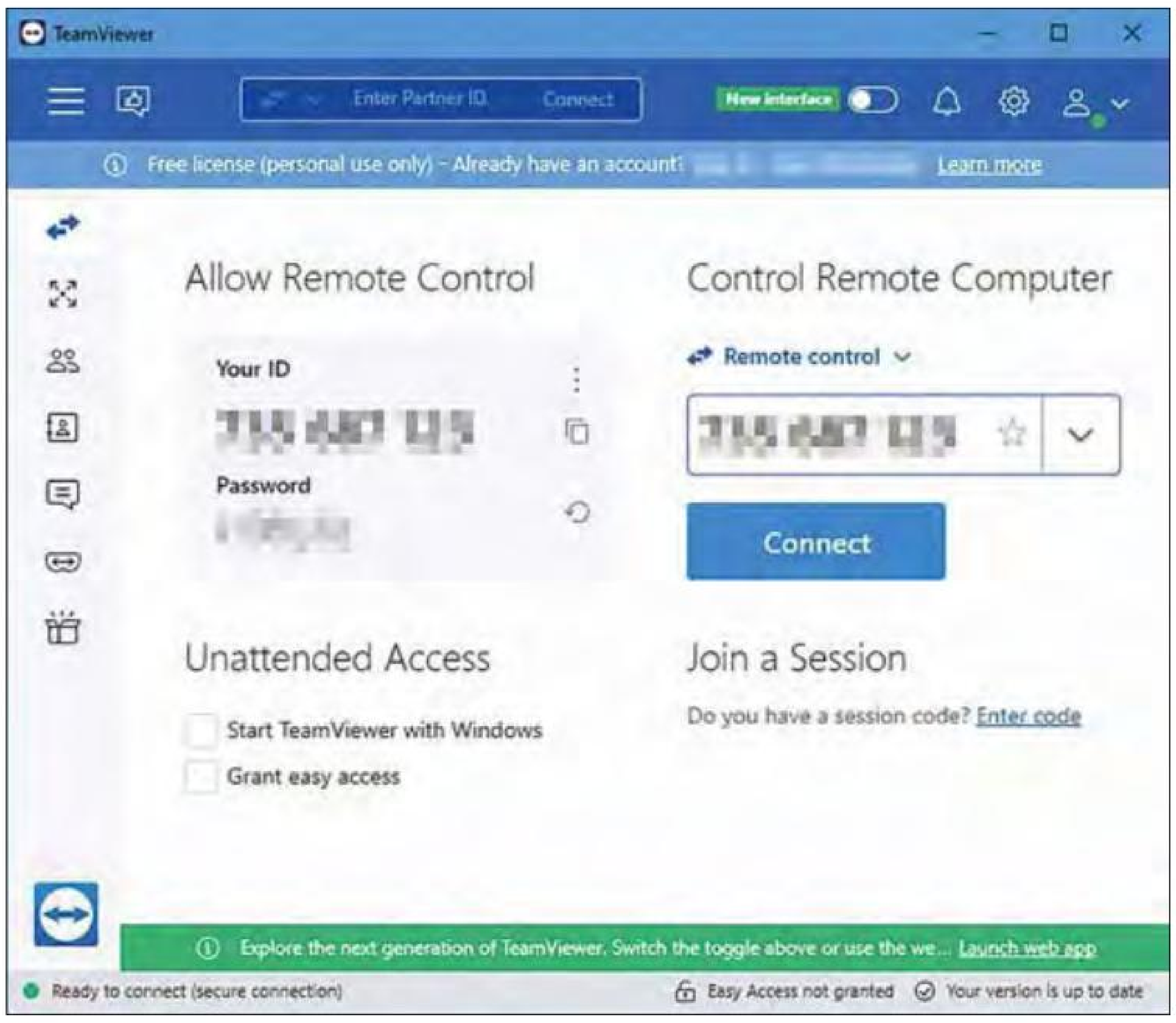
I found this latest cordless mouse was smaller, more lightweight and a lot more skittish than my old MX1000, but it also demonstrated the current state of the art in cordless mice design: instead of using a docking station to recharge an NiMH battery, the mouse holds a single AA battery giving up to 20 months' operation; I use a (non-rechargeable) Energiser Ultimate or VARTA Ultra Lithium AA cell, which I expect will give several years of service.

The connectivity side is steeped in Logitech's trendy marketing jargon. Being cordless, a tiny USB receiver called the 'Logi Bolt' is supplied for PC use, but the same mouse can also use Bluetooth to connect to, say, a laptop or tablet. In this mode, Logitech says it's compatible with Windows 10+, macOS 10.15+, Linux, ChromeOS, iPadOS 13.4+, Android 5.0+ and Evo Laptops.

For PC users, their 'Logi' software is installed, but instead of good old-fashioned drivers, users are offered 'Logi Options+' which it describes as the 'next gen app for your mice and keyboards'. It seemed to install without a hitch, but I strongly dislike the sprawling software which takes up far too much unnecessary white space on screen and displays a bad case of designer-itis. Fortunately, you won't need to use it very often.

After some tweaking and localisation ready for its new home overseas, the PC was ready for shipping, complete with its new mouse. A few weeks later, I received an urgent call for help from the PC's new owner – the Logitech mouse had suddenly stopped working and she urgently needed to print off a business document. An ordinary wired USB mouse would help at such times, but one wasn't available.

While searching desperately online for a user manual and FAQs, I found


TeamViewer
Enter Partner ID
Connect
New interface
Free license (personal use only) – Already have an account?
Learn more
Allow Remote Control
Your ID
Password
Control Remote Computer
Remote control
Connect
Unattended Access
Start TeamViewer with Windows
Grant easy access
Join a Session
Do you have a session code? Enter code
Explore the next generation of TeamViewer. Switch the toggle above or use the we... Launch web app
Ready to connect (secure connection)
Easy Access not granted
Your version is up to date

TeamViewer is among the best remote networking programs and it's free for personal use.

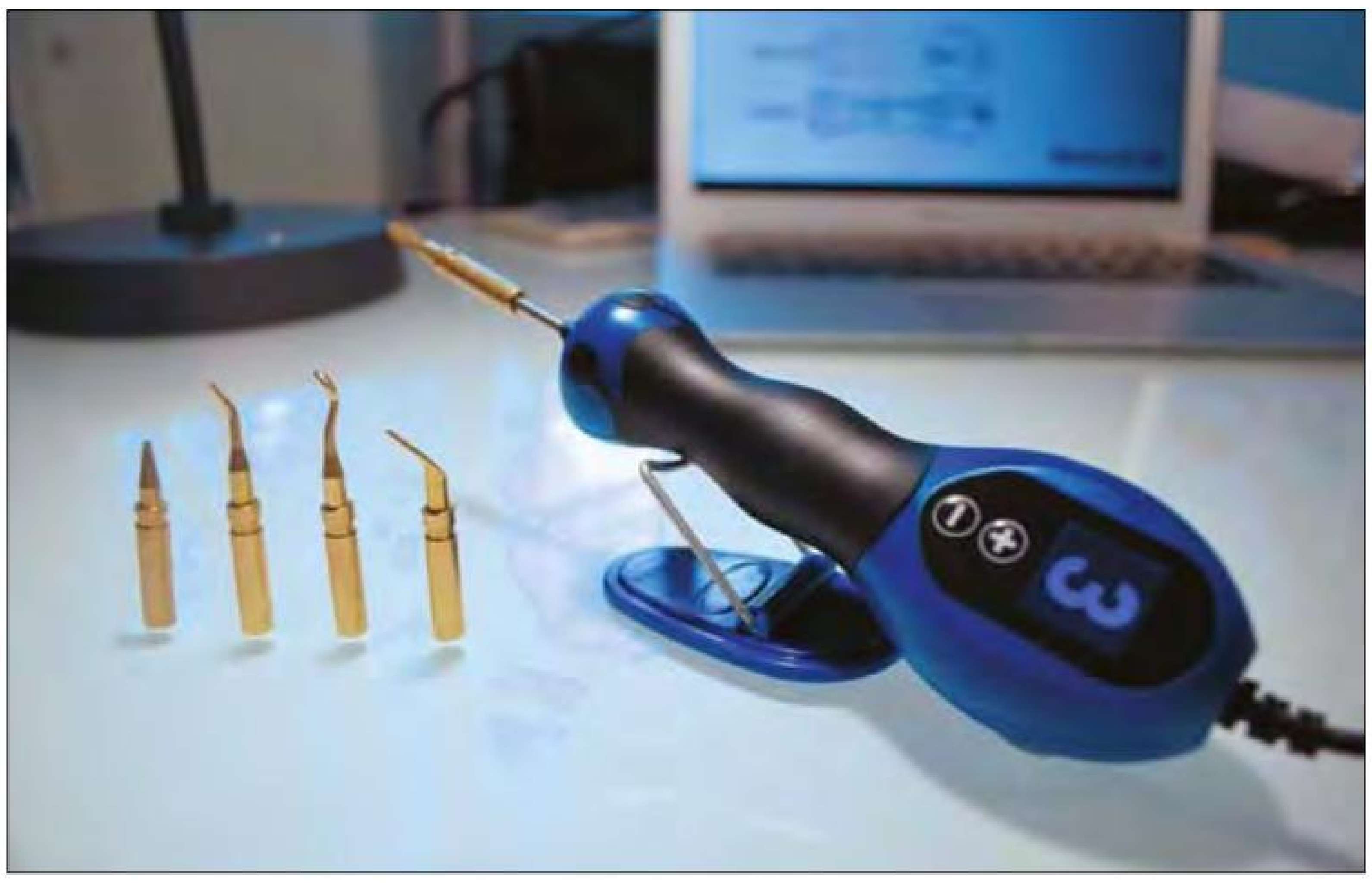
Logitech's sprawling, over-designed website exasperating: their diagram of mouse buttons and features had no key to identify which is which, so I had to try describing to the user over the phone which buttons to try pressing next. The Logi software displayed a forlorn 'Fix Device' and a trash-can symbol, which would presumably delete the mouse altogether. I finally gave up when Logitech's online support suggested the user opens and checks the Windows Device Manager for errors: how can you, if the mouse doesn't work? (The answer is that you can, by typing Winkey + R to open a Run box, type `devmgmt.msc` and hit Enter – not that it would have helped anyway.)

With the clock ticking away, I had one last stab at fixing the problem: I suggested unplugging and re-connecting the tiny USB 'Bolt' receiver again, on the back of the PC. She followed the directions and, lo and behold, the mouse immediately sprang into life again! The documents were then printed off just in the nick of time. I suggested she also goes and buys a cheap spare mouse from the supermarket, just in case.

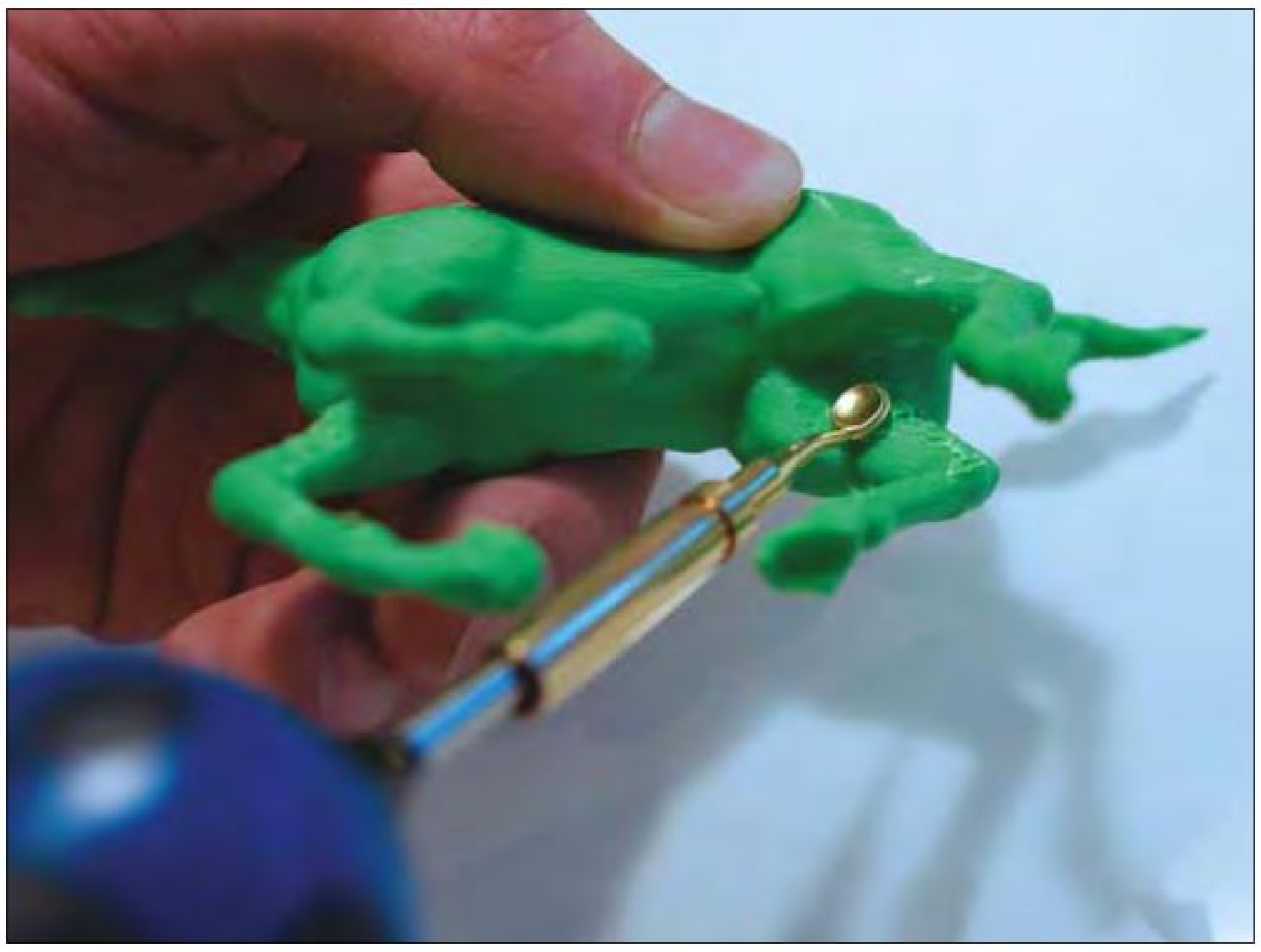
At other times, using remote access would allow me to log in and operate the PC as though I was sat in front of it, and TeamViewer has helped me to sort out PC problems remotely many times this way. Generously, TeamViewer is free for occasional personal use, although it's now necessary to set up an account beforehand. TeamViewer has also suffered from bloated software designer-itis and it now has a sprawling interface that takes up a lot of screenspace for no good reason. Fortunately, users can easily revert to the old interface, which I very much prefer. You can download the program from: **https://teamviewer.com**

In other news

Antex Electronics, the UK-based manufacturer best known for its soldering equipment, has launched a hot tool designed for reworking and trimming 3D-printed objects. The Retouch3D is the world's first heated tool to finish 3D prints, Antex says, and it has variable heat settings and interchangeable heads for specific 3D retouching and finishing tasks. Included are an international mains adaptor and various shaping tips. The new tool can be purchased from: **https://bit.ly/pe-nov23-antex**



Antex Electronics has launched the world's first heated tool for finishing 3D prints. A toolkit of tips and stand are included.



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ISRO's Pragyan Rover snaps the Vikram lander at the south pole of the Moon (ISRO/X)

In August, the Indian Space Research Organisation (ISRO) saw its Chandrayaan-3 spacecraft (translated as 'Moon Vehicle 3') complete a flawless historic mission. This ambitious project placed a lunar lander at the Moon's south pole, making India only the fourth country to land on the Moon and the first country ever to explore the south pole. The moon lander, named Vikram after Vikram Sarabhai, the ISRO's founder, carried the Pragyan Rover, which is shown exiting the lander at: **https://youtube.com/shorts/cYXMQ4UjjSk**

Both the lunar lander and rover were then hibernated and a re-awakening was expected around 22 September. In-depth details of the mission's objectives and its equipment payload are at: **https://bit.ly/3LqsBfy**

The Indian craft's soft-landing celebrations are shown on YouTube at: **https://youtu.be/DLA_64yz8Ss**

At the same time, Russia's Luna-25 mission, also aiming at the south pole in August, was unfortunately lost during its final approach. Japan has just launched its own moon mission, the 'Moon Sniper' which should land next February. They hope to place the SLIM (Smart Lander for Investigating Moon) vehicle within 100m of the intended target.

SpaceX's Starlink is launching Starlink Mobility, a satellite-based data service aimed at enterprise mobile users such as trucks, buses and emergency services. The service offers downloads of up to 220Mbps and the ruggedised hardware will withstand pretty much everything the elements can throw at it. The price is strictly business-class, starting at £247 per month and a one-off hardware cost of £2,410, with a 30-day money back guarantee. More details at: **www.starlink.com/mobility**

The Chinese electric VTOL air-taxi maker AutoFlight (*Net Work*, April 2022) has flown the world's first formation of three generations of their Prosperity eVTOL aircraft. The full-size prototypes flew together for about 50 minutes at various heights, as shown at: **https://youtu.be/_4eZ1LU2iFs**

The first certified aircraft should carry cargo next year and a passenger taxi version is promised later.

In the US, a 6-motor electric aircraft is currently undergoing FAA certification. The aircraft, built by Joby Aviation, would carry four 'ridesharing' passengers and a pilot, see: **www.jobyaviation.com**

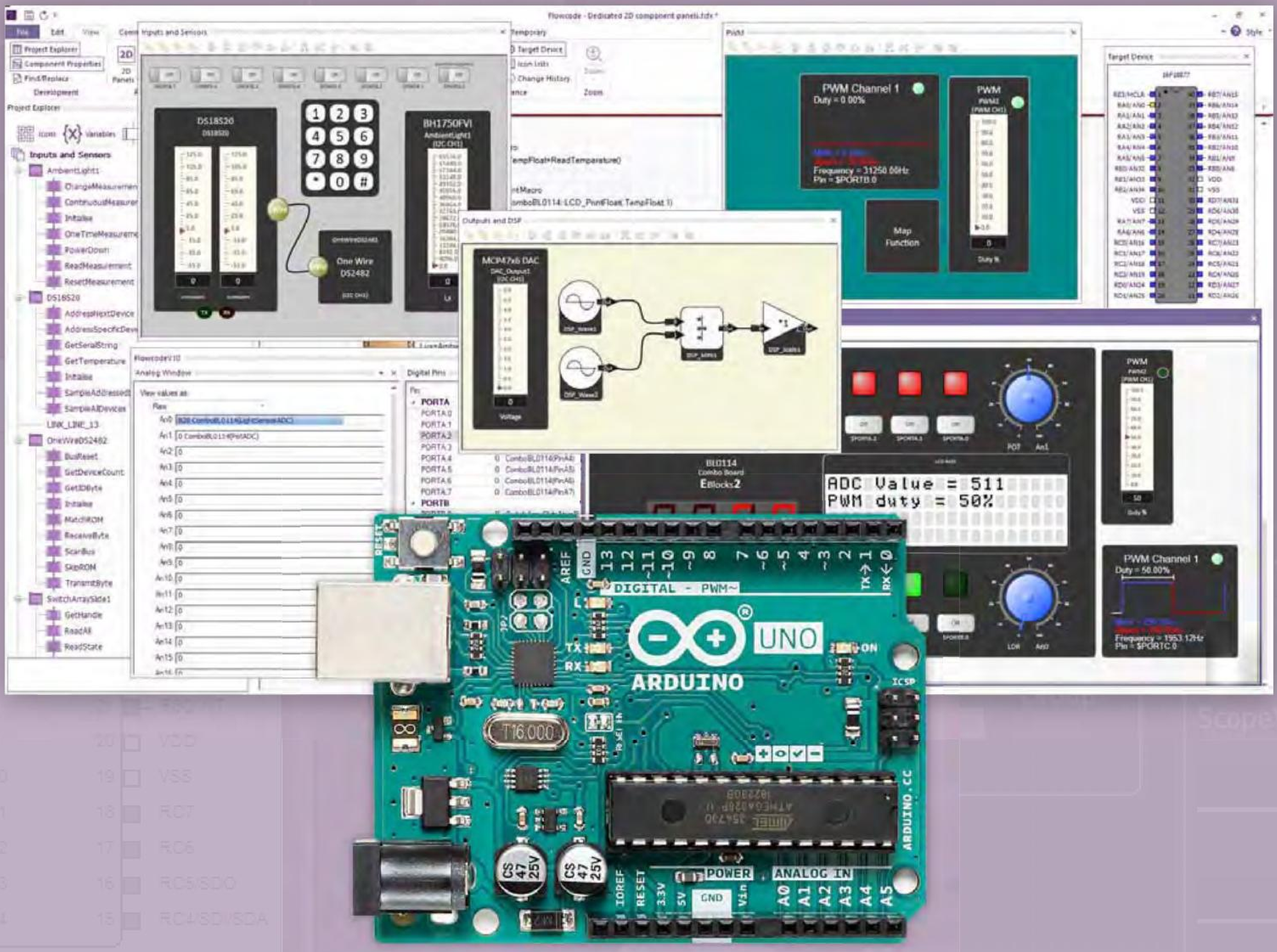
Meanwhile, UK-based Vertical Aerospace suffered a setback when an unmanned prototype VX4 eVTOL craft fell to a runway from a height of about six metres during extreme testing. Details of the impressive aircraft can be seen at: **https://vertical-aerospace.com**

Last this month, users of Microsoft's Windows Mail, the email program built into Windows, will gradually be migrated to Outlook starting in 2024. New Windows 11 systems will start to ship with Outlook installed by default, but the Windows Mail app will still be available for download for the next year. Outlook for Windows will be free – more at: **https://tinyurl.com/mwp28rs9**

That's all for this month's *Net Work*. Don't forget that the above links will be ready-made for you in the *Net Work* summary blog on our advert-free website at: **www.electronpublishing.com**

The author can be reached at:
alan@epemag.net

AutoFlight displayed the world's first formation of three eVTOL aircraft, which flew for 50 minutes at various altitudes. (Two eVTOLs shown.)



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The Fox *Report*

Barry Fox's technology column

Time is money

The real cost of buying a better computer is not the cost of the hardware, but the cost in time of installing all the software, and tweaking all the settings, to make it work like the old one.

There's also the cost of buying the keys needed for replacement software that requires activation. No one has yet cracked the challenge of stripping everything off one device and automatically installing it on a different one. They probably never will because the software companies want to sell new keys.

A word to the wise

This, of course, is why more and more people are using tried and tested Open Source free and donation-based alternatives to proprietary programs – like LibreOffice, Wordpress, GIMP, Shotcut, Avidemux, VLC, Squoosh, OBS Studio, Handbrake, Audacity, 7-Zip, J-Downloader, and the many Google Apps like Contacts, Photos and Drive.

To the best of my knowledge, based on many years of hands-on use, all the afore-mentioned 'free' programs are safe. But, do try to download them direct from the developers' sites, or established repositories like GitHub and SourceForge, not pop-up third party sites that may try to trick-sell what's free. Also be careful not to click on diversionary download links that lead to unwanted and often trial installations of completely different software.

New disks for speed

Attempting to upgrade an old PC has until recently been largely unrewarding. Adding more hard drive disk (HDD) space, either by replacing existing HDDs with discs of larger capacity, or plugging in external USB HDDs, does nothing to accelerate. Adding more RAM may speed up performance, a bit, but requires care to match module type.

The most dramatic speed boost comes from replacing an 'old-fashioned' spinning disc HDD with a new solid-state drive (SSD). Over recent months the price of SSDs has fallen dramatically – under £50 for 1TB. (But see the end note about the need to guard against fake storage of all kinds, including SSDs.)

From recent practical, personal tests, based on replacing the spinner HDD in a painfully slow old Windows 10 Dell Optiplex desktop PC with a new SSD, I can vouch for how easy it is for anyone with some basic DIY IT skills. Of course, this advice comes with no guarantees, just practical guidance on how to swap out and how to safeguard yourself if something does not work.

SATA, SATA, SATA

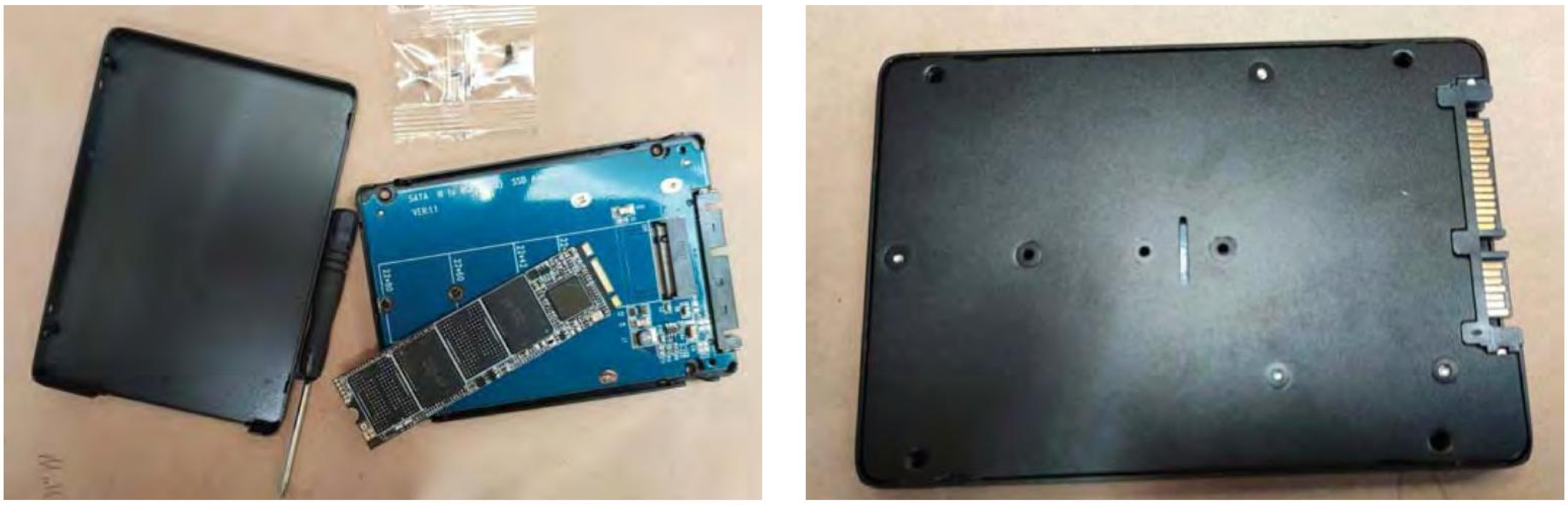
The easiest way to upgrade from an old 'spinner' HDD to SSD is simply to buy an SSD with SATA sockets and use it (with a SATA-to-USB casing or adaptor) to clone the existing operating system. For this, use backup software (like Macrium) which offers a full system clone option.

Everything is easier if the old HDD spinner is of low capacity (a few hundred GB) because it will then be of the same or smaller capacity than an affordable SSD. This makes it much more straightforward to clone. If the spinner HDD is of large capacity you may need to move non-essential data off it and then 'shrink' its partitions using disc management software, before cloning. Unless you are skilled in disc partition management, or are prepared to become skilled, shrinking can be daunting and stressful.

Once the cloning is done, just swap the SATA leads in the computer from the old to new drive and, if necessary, change the boot sequence by accessing the BIOS (by pressing F10, or whatever function key your PC requires, at boot-up.)

Be sure to keep the original 'old' HDD untouched so that if there are any problems you can then simply re-plug the SATA leads back to the original state. Later, when all is proven good, you can reformat the original HDD for use as a data drive. But wait a good while before taking this final step.

The more adventurous may wish to cut costs by buying a bare SSD circuit 'stick'. Two memos (both borne out of mistakes I have made) may help here because, confusingly, there are different kinds of SSD stick, both look similar and both resemble a RAM card; and there are different kinds of adaptor/casing. To put it as simply as possible:



An M.2 NGFF SSD 'stick' and SATA case. Fitting is straightforward but fiddly. A magnetic screwdriver helps with the tiny screws. The 1TB SSD was surprisingly cheap. Just £18 post free. It will need rigorous capacity testing before it can be trusted with data – and that will take around 24 hours to complete.

- Both SSD stick types have the same M.2 physical form factor.
- An M.2 NGFF (Next Generation Form Factor) SSD stick connects to a SATA bus, as used by conventional HDDs, via a SATA adaptor or SATA casing.
- New PCs and devices (like newer network attached storage (NAS) boxes) come with an internal NVMe (Non-Volatile Memory Express) socket for direct connection to an M.2 NVMe SSD stick.
- There are various types of adaptor casing for both kinds of stick, namely (old) M.2/NGFF and (new) NVMe. One kind of adaptor casing is for SATA connection of an NGFF SSD, and another is for USB connection. If you are swapping an old HDD for a new SSD, then you will need a case with SATA connection.
- It's easy to get muddled by the adverts and buy the wrong type of stick and/or casing – I've done it. Carpenters measure twice before cutting – check SSD descriptions equally carefully before ordering.

Moving on from my mistake setback, I successfully used Macrium backup software with an SSD stick in a SATA casing to clone the OS from the low capacity HDD in the old snail-pace Dell. The 'SATA'd' SSD then straight-replaced the Dell's HDD. The acceleration was quite magical.

Warning

- When cloning, it's easy to fall into the trap of picking the wrong source and destination drives and end up wiping the original operating system. Again, think like a carpenter and double-check before clicking 'OK'.
- If you are nervous, make an ordinary full system image back-up copy of the original HDD onto a separate HDD before cloning to SSD.
- And I repeat: Keep the original OS on the original spinner HDD for easy swap-back until you are sure that all is working well.

I plan now to experiment with another spinner PC, using an M.2 NGFF SSD stick in a SATA casing. But first, I need to research and report here on a separate trap for the unwary.

Not all memory is equal

Fake memory devices, including SSDs, are widely on sale. Their controller chips have been cleverly programmed to return a misleadingly high capacity – eg,1TB instead of 256GB. The real memory is then over-written by new data.

Software that checks and displays fake values is readily available, for free, but it is inevitably slow and often awkward to use. I have bought some suspiciously cheap 1TB SSDs and will now look for the easiest way to check their real capacity and – if necessary – return them to the sellers.

Going underground

Wi-Fi access on the London Underground has always been a moveable feast. The latest movement is very much in the travellers' favour.

Access has previously been available (on platforms, not tunnels yet) to paying subscribers to the main comms networks (O2, Three, Vodafone, Virgin, EE) not the cheaper networks (Giff Gaff,1pMobile) which ride on the back of the majors. PAYG users of the major networks have only been able to connect if they have recently topped up.

All change

But all that has recently changed, with haphazard new rules of engagement. Perhaps because the need to check in real time who has paid what and when is too difficult and takes too much time to complete, access has now been thrown wide open. Don't bother asking the networks for hard-fact information; shop staff will just look blank or give conflicting and confusing advice. Just try it yourself on a platform and see what works for you.

Currently (and who knows how and when it will be all change again) the major Wi-Fi networks such as Vodafone, Three and Wi-Fi Extra (O2) which a phone almost always finds at all stations, now seem to be providing free access for all. No passwords are needed, although with Wi-Fi Extra the PEAP (Protected Extensible Authentication Protocol) option should be set to SIM.

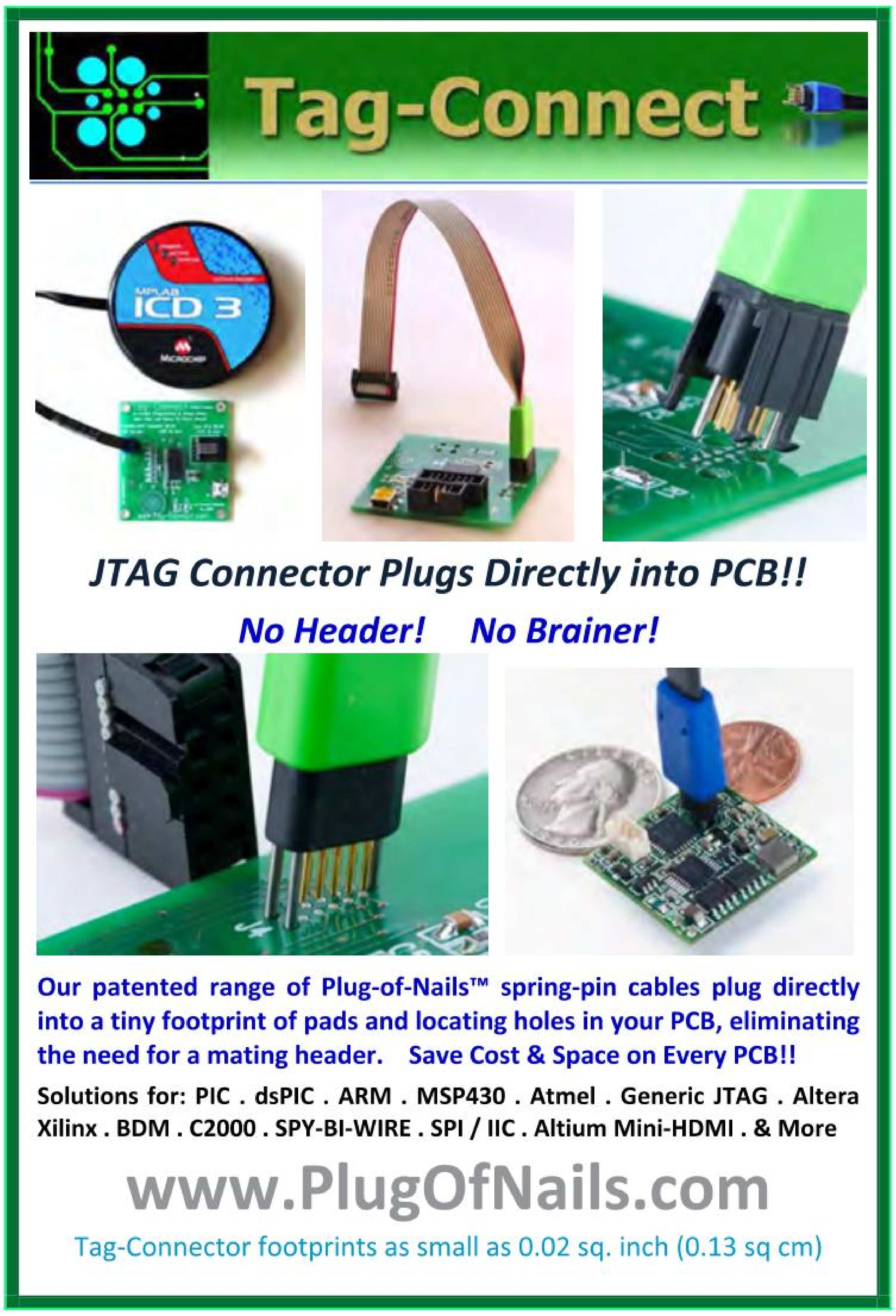
UNDERGROUND

I have no SIM of any kind for Vodafone or Three, but both let me in. I have an O2 SIM which has not been topped up recently but that still talks to Wi-Fi Extra.

VOIP to home or office

Apart from enabling emails and social messaging, underground Wi-Fi makes it possible to make speech calls ('I am running late because there are tube train holdups') by using VOIP (Voice over Internet Protocol) and the live-talk features offered by systems like Skype, WhatsApp and Telegram.

Experimenting with what works with free Wi-Fi is a wonderful way to while away time when 'trapped' underground. However, do remember that although it is unlikely a scammer could rig a phoney Wi-Fi hotspot deep underground, to steal sensitive data like bank details, it is good policy never to send anything sensitive via a public Wi-Fi hotspot.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OPTION 1
NORMAL
OPTION 2

- **Capacitance Range:** 1pF to 1200pF+ with 0.1pF resolution
- **Inductance Range:** 100nH to 2500µH+ with 10nH resolution below 10µH
- **Accuracy:** typically better than 2%
- **Power supply:** 3 × AA cells, draws ~35mA during operation
- **Battery Life:** around 72 hours with fresh alkaline AA batteries; operates down to 0.6V per cell
- **Display:** 0.96-inch (24mm diagonal) OLED screen

LC Meter Mk3

This LC (inductance/capacitance) meter is a modern version of an old design – the Tektronix T130 from the 1950s. It measures a wide range of capacitances and inductances, from less than 1pF to more than 1.2nF, and from less than 100nH to more than 2.5mH. It displays the results on an OLED screen.

By Charles Kosina

I was inspired to design this modern LC Meter when I read about the 1954 Tektronix Type 130 LC Meter in a series of articles by Alan Hampel. It was impressive engineering for the time, using all-analogue techniques.

While many cheap LC meters are available today, their main drawback is not being able to measure low values. RF filters often require accurate values less than 10µH or 10pF.

The Tektronix design had a reference oscillator at 140kHz (F_{REF}). The measurement oscillator (F_{TEST}) was initially tuned to the same frequency. Then, by placing a capr across the tuned circuit, or an inductor in series with the inductor in the oscillator, the test oscillator frequency dropped.

Mixing the two signals gave signal components at frequencies $F_{REF} + F_{TEST}$ and $F_{REF} - F_{TEST}$. Selecting the latter using a low-pass filter, the T-130 used clever analogue techniques to convert this to a capacitance or inductance value shown on a moving coil meter. Their design gave accurate measurements from 1–300pF or 1-300µH.

It was all done using valves; transistors were not available back then.

My first *LC Meter* design emulated much of this principle and worked reasonably well, but that version had some deficiencies. It used two variable capacitors, a coarse and fine adjustment, to set the test frequency to the exact value before a capacitor or inductor was measured. This was time-consuming and fiddly, so I added an 'automatic zero' on power-up.

Also, its construction was complicated, using a large LCD, so I changed it to use the same OLED screen that I used for my *AM-FM DDS Signal Generator* (*PE*, May 2023) and *0-110dB RF Attenuator* (*PE*, July 2022).

The OLED screen is cheaper and also consumes a lot less power. That allows the *LC Meter* to run for many hours on three AA cells and operate down to a total battery voltage of 1.8V (0.6V per cell) thanks to the use of a step-up regulator. That will save on battery costs.

After making those changes, I had a *LC Meter* that worked well, but I felt it was still too complicated and used too many parts, some difficult to source. The auto-zero function took far too long, and the accuracy and resolution were worse than I would like. Calibration was problematic as well.

I solved all those problems in my final design. It somewhat moves away from the original Tektronix concept by not starting at a particular frequency. The operating frequency is now of secondary importance as it gets cancelled out in the calculations. It is also self-calibrating, yielding an accuracy of about 2% over the whole capacitance range.

The capacitance range is now 1pF to more than 1200pF with a resolution of 0.1pF, while the inductance range is 100nH to more than 2500µH with a resolution of 10nH below 10µH.

You might notice that this new auto-calibrating concept makes it somewhat similar in operation to our June 2017 *Arduino-based Digital LC Meter*, which was based on an even earlier *High-accuracy Digital LC Meter*.

However, those designs use a comparator in the oscillator and that causes some problems and has limitations. As you will see when we get to the circuit, the implementation of this *LC Meter* is somewhat different. It uses a separate inverter-based oscillator and has self-calibration features to provide better accuracy over a wide range of component values.

Parts availability

Sourcing components is always a problem these days, but I went to quite a bit of effort to ensure that everything was available from element14 at the time of writing. There are a few parts that are available from multiple AliExpress sellers at very low prices. However, for some of these, you may have to buy multiple quantities. Still, as the prices are so low, you will end up with plenty of spares.

Performance

One primary object of this design was to produce accurate readings for low-value inductors. VHF filters generally require inductors in the sub-1µH (ie, nanohenry) range.

I have an ancient Q-Meter, a Meguro MQ-160. The design dates back to the 1940s; the one I have was made in 1969. It still works quite well, as long as the valves inside keep functioning.

The MQ-160 came with a box of 14 calibration inductors from 1μH to 25mH. They are all large air-cored coils and are really works of art. Their accuracy would not drift with time, so they continue to be a good standard.

Using individual and series combinations of my standard Meguro inductors, I obtained the accuracy figures shown in Table 1.

These assume my test coils are accurate, as there is no specific information in the Meguro manual about their accuracy. The accuracy for capacitor values depends on how close the 1% calibration capacitors are, and can therefore be assumed to be no worse than ±2% (and probably closer to ±1%).

At the measurement frequency of 600kHz or less, ferrite-cored inductors all read low as the ferrite permeability is reduced at lower frequencies. For example, a nominal 68μH inductor measured 58.5μH at 572kHz, but a 1μH inductor fared much better and measured 0.89μH at 630kHz. Air-cored inductor measurements will not vary significantly with frequency.

Circuit details

The *LC Meter* circuit is shown in Fig.1. It is based on a Franklin oscillator comprising two 74HC04 inverters, IC2a and IC2b. The 1MΩ resistor across the first inverter puts it into a linear mode, making it act like a very high gain inverting amplifier. The second inverter provides the phase shift, which feeds back into the tuned circuit.

Table 1 – inductance accuracy

Meguro inductor	Measured value
1.0μH	0.98μH
2.5μH	2.53μH
5.0μH	4.88μH
★7.5μH	7.35μH
10μH	9.94μH
★15μH	14.2μH
25μH	24.4μH
★35μH	34.6μH
50μH	49.8μH
★75μH	75.1μH
100μH	99.8μH
★150μH	148μH
250μH	254μH
★350μH	357μH
500μH	492μH
★750μH	750μH
★1000μH	1009μH
1250μH	1250μH
1500μH	1484μH
2500μH	2498μH

★ *made by connecting two coils in series (eg, 150μH = 100μH in series with 50μH)*

With the nominal onboard 330μH inductor (L1) and 220pF capacitor, the oscillation frequency is about 630kHz. It has a large operating range and will still oscillate reliably with more than 1200pF added across the tuned circuit or up to 2.5mH in series.

One advantage of this arrangement is that the output of IC2b swings between the supply rails. This means that it does not need an additional fast op-amp to boost the signal into a range that a microcontroller can easily measure.

Four transistors, Q1-Q4, switch additional capacitors across the tuned circuit. These capacitors are 1% tolerance types, and by using parallel combinations, we get ten calibration points. The BFR92P transistors used here have very low collector-to-base and collector-to-emitter capacitances, typically 0.4pF and 0.23pF, respectively, so they will not detract from the accuracy.

The base resistors for these transistors are 3.3kΩ, and with 5V applied, they drive the transistors well into saturation, providing low-impedance ground connections for the capacitors.

We need to provide a 'zero reference' point for inductance measurement. This is done by connecting L1 to ground and measuring the oscillator frequency. My initial design used an NPN transistor for this, but once the inductance under test got close to 1000μH, the voltage across the switched-off transistor was such that its reverse-biased junction conducted and clipped the waveform.

The solution was to substitute a small relay (RLY1). That allows the *LC Meter* to measure up to at least 2.5mH.

DPDT switch S2 selects between capacitance (up) and inductance (down) measurements. For capacitance measurements, the DUT is placed across the tuned circuit, while the DUT is placed in series for inductance measurements. In both cases, the oscillation frequency will be reduced.

The oscillation frequency is too high for the microcontroller to measure accurately, so a 74HC161 binary counter is used to reduce it to less than 100kHz. In the initial design stages, I was not sure how much division would be needed, so header JP1 gives the option to divide by 2, 4, 8 or 16. In the final design, a division ratio of eight is used.

Microcontroller and display

The processor used is the ATMega328P on the Arduino Nano module (MOD1). I chose it as it is cheap and readily available from multiple sources, including eBay and AliExpress. It also simplifies the construction substantially.

Its INT0 interrupt pin (pin 20) is used to count the frequency from the oscillator. For capacitance measurements, a 250ms window is used to count pulses. However, this is increased to two seconds for inductance measurements to obtain enough resolution down to 10nH.

The OLED screen is controlled over a two-wire I^2C (inter-integrated circuit) serial interface. Because this uses open-drain style signalling, no voltage translation is needed, just 15kΩ pull-up resistors to +3.3V. These values are higher than the usual 4.7kΩ to reduce power consumption further. With the short tracks, there is no problem with noise, despite the lower bias current.

One analogue input on the micro is used to measure the battery voltage, while the other is used to sense the three-position function switch, S1.

Momentary switch S3 is used for starting capacitance calibration or for inductance measurement.

There is an optional output for a buzzer at CON4. This gives a beep when calibration is completed. As this is its only function, it may be safely omitted. The series diode is a safety feature as the connector is the same as for the battery input. Without the diode, if the battery was connected to the wrong socket, it could destroy the microcontroller.

I always have a simplified RS-232 serial connection on my boards for debugging the firmware. In this case, the three unused 74HC04 inverters are used, with two in parallel for the TX pin to provide sufficient drive strength. The serial interface format is 38400,8,1,n and lots of debug information is transmitted, which I have left in, as it does not slow down the operation.

Power supply

REG1 is an MCP1661 or MP1541 step-up voltage converter. It can operate with an input voltage below 2V and still provide the required 5V output. While two cells will provide enough voltage, by using 3 AA cells, the minimum voltage is less than 0.7V per cell. You can use up all those cells which no longer work in a mouse or other equipment to power the *LC Meter*, saving a little money.

REG1 works by pulling its switch pin (pin 1) low, in pulses at 500kHz. When this pin goes low, current flows from the battery through inductor L2, to ground and back to the battery, charging up L2's magnetic field.

When the transistor pulling pin 1 low is switched off, current flows from the battery through L2 and schottky

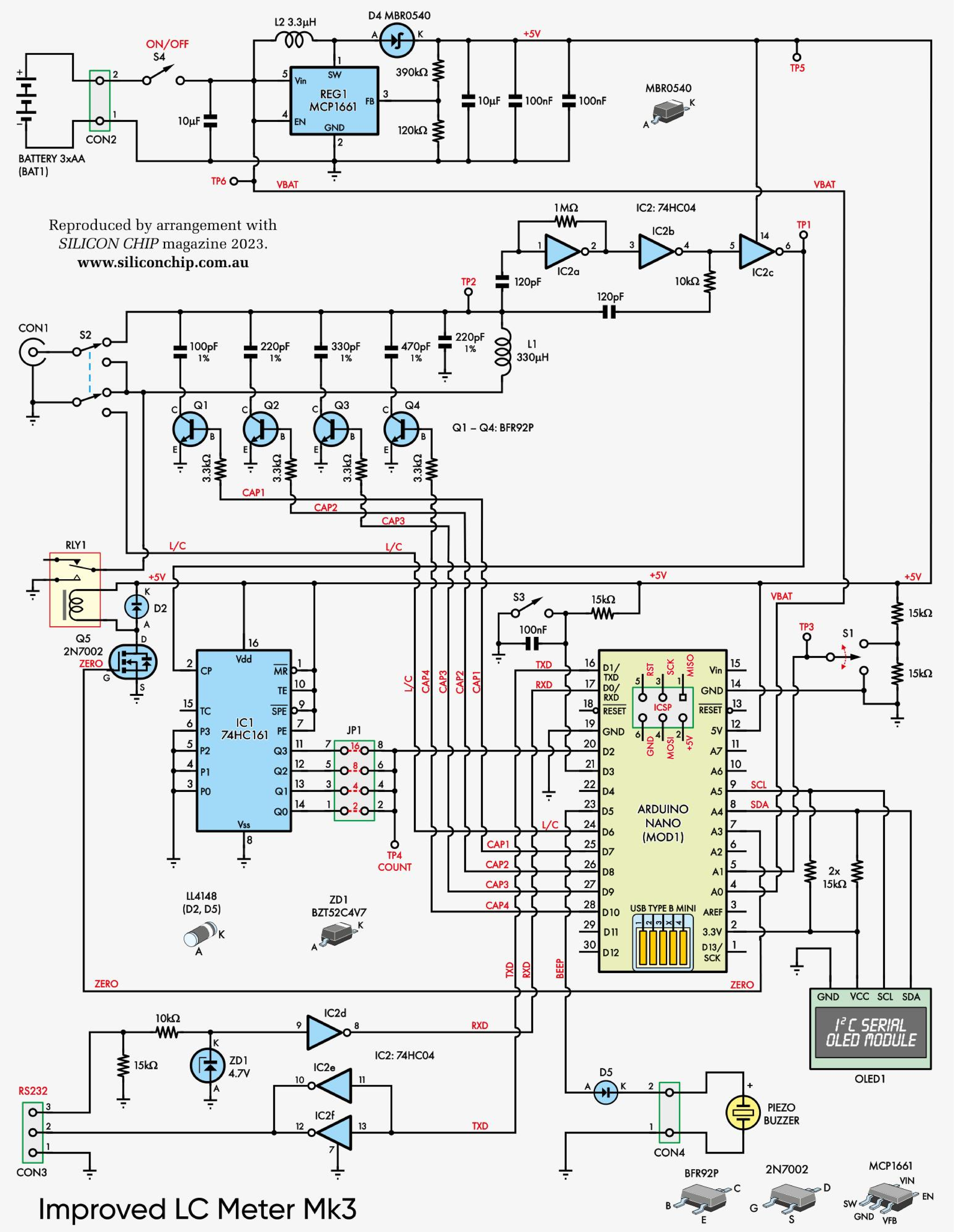
Improved LC Meter Mk3
BATTERY 3xAA (BAT1)
CON2
ON/OFF S4
L2 3.3µH
D4 MBR0540
REG1 MCP1661
Vin
SW
FB
EN
GND
10µF
390kΩ
120kΩ
10µF
100nF
100nF
+5V
TP5
TP6
VBAT
MBR0540
1MΩ
IC2: 74HC04
IC2a
IC2b
IC2c
TP1
TP2
120pF
10kΩ
120pF
CON1
S2
100pF 1%
220pF 1%
330pF 1%
470pF 1%
220pF 1%
L1 330µH
Q1
Q2
Q3
Q4
Q1 – Q4: BFR92P
3.3kΩ
CAP1
CAP2
CAP3
CAP4
L/C
RLY1
D2
Q5 2N7002
ZERO
IC1 74HC161
Vdd
Vss
CP
TC
P3
P2
P1
P0
MR
TE
SPE
PE
Q3
Q2
Q1
Q0
JP1
TP4 COUNT
S3
15kΩ
100nF
TXD
RXD
BEEP
ARDUINO NANO (MOD1)
ICSP
RST
SCK
MISO
GND
MOSI
+5V
USB TYPE B MINI
D1/TXD
D0/RXD
RESET
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
Vin
5V
A7
A6
A5
A4
A3
A2
A1
A0
AREF
3.3V
D13/SCK
SCL
SDA
TP3
S1
15kΩ
15kΩ
2x 15kΩ
GND VCC SCL SDA
I²C SERIAL OLED MODULE
OLED1
LL4148 (D2, D5)
ZD1 BZT52C4V7
RS232
CON3
10kΩ
15kΩ
ZD1 4.7V
IC2d
IC2e
IC2f
IC2: 74HC04
D5
CON4
PIEZO BUZZER
BFR92P
2N7002
MCP1661
VIN
EN
SW
GND
VFB

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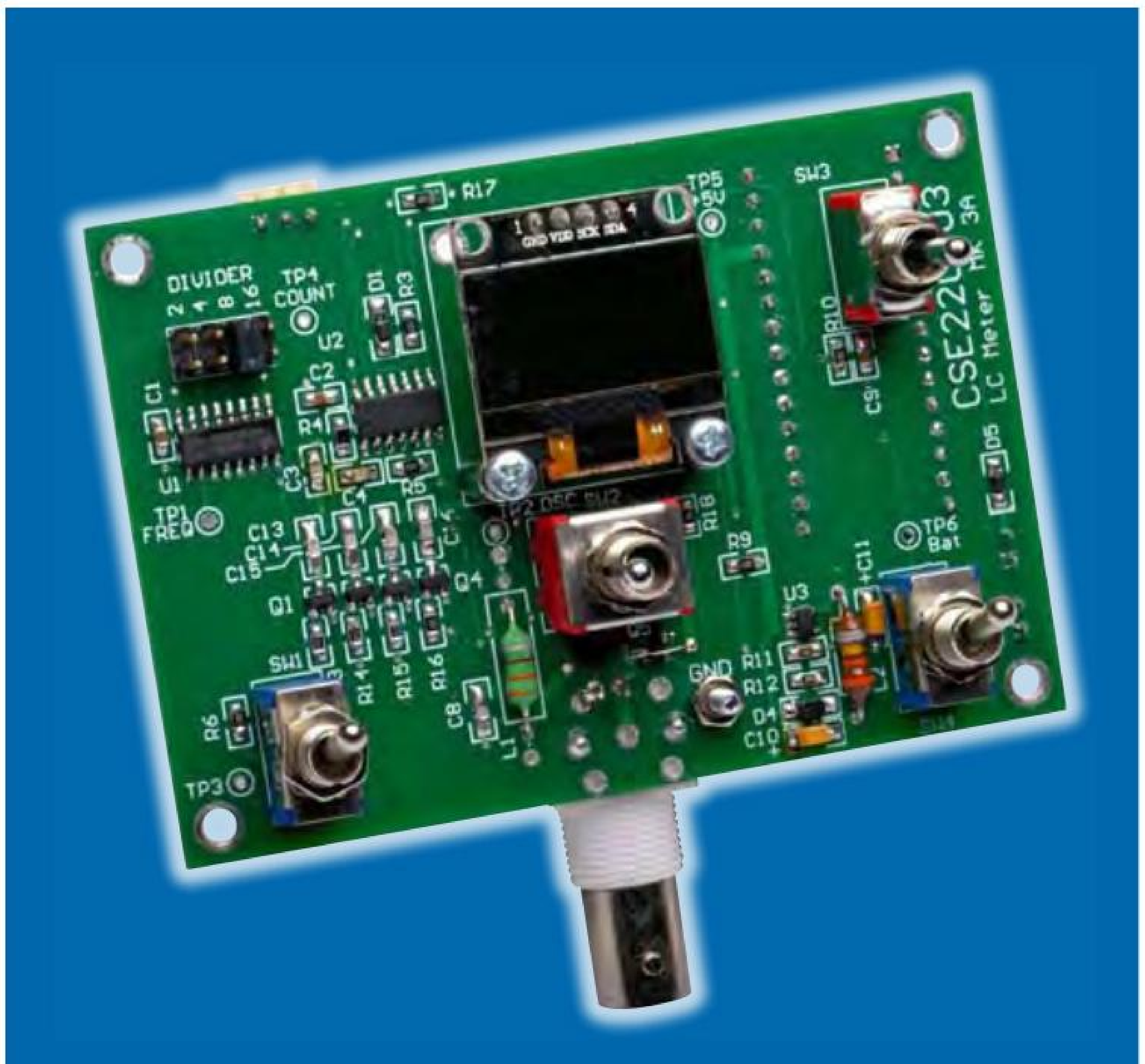
Fig.1: the primary oscillator is built from inverters IC2a and IC2b. Its frequency is affected by an external capacitor/inductor at CON1, or onboard calibration capacitors switched by transistors Q1-Q4. Inductor L1 is used for measuring inductances, switched to ground by RLY1. The Arduino Nano controls and monitors the oscillator, computes the values and displays them on a small OLED screen.

diode D4 into the 5V supply rail, powering the circuit and charging up the filter and bypass capacitors. As L2's magnetic field collapses, the voltage at the anode of D4 rises above the battery voltage.

By controlling the duty cycle of the pulses, REG1 maintains the voltage at its V_{FB} (feedback) pin close to 1.227V. The division ratio of the 390kΩ and 120kΩ resistors causes this to be effectively multiplied at the top of the divider. This



The prototype lacks the relay and associated components, but otherwise is very similar to the final design.

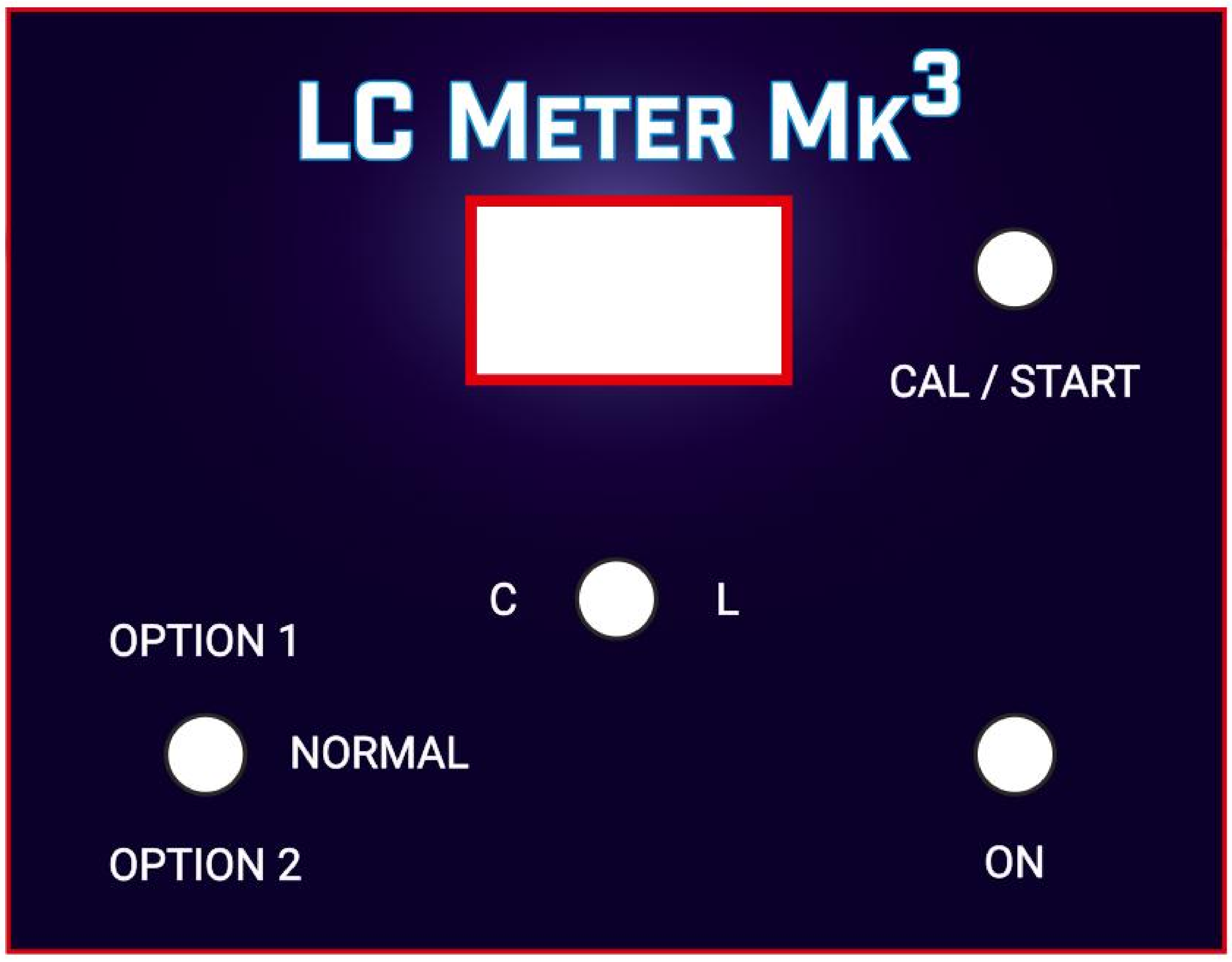


Fig.8: the front panel label can be downloaded from the November 2023 page of the PE website at: https://bit.ly/pe-downloads and printed on photo paper. There are two versions available, one with the OPTION switch at lower left (shown here) and one without it.

results in an output of 1.227V × (390kΩ + 120kΩ) / 120kΩ = 5.215V.

Measurement calculations

The frequency of a tuned circuit is given by $C = 1/\omega^2 L$ and $L = 1/\omega^2 C$, where $\omega = 2\pi f$. For C in pF, L in µH and f in MHz, this simplifies to the useful equations $C = 25330/f^2 L$ and $L = 25330/f^2 C$.

If we know the inductance value by measuring the frequency, we can calculate the capacitance, but this method has two problems.

First, an accurate inductor is not available; the best we can get is ±5%. Secondly, suitable inductors are on a ferrite core and, as mentioned earlier, permeability varies substantially with frequency. It is impractical to use an air-cored inductor as it would be too large.

This is where the calibration technique results in accurate measurement. On power-up, the oscillator frequency is measured first with transistors Q1 to Q4 off.

This gives the frequency with no external capacitance. Then by switching on the transistors in different combinations, we get calibration points of 100pF, 220pF, 320pF, 470pF, 690pF, 790pF, 940pF, 1040pF, 1160pF and 1260pF.

Fig.2 shows the curve derived from these calibration points with the frequency offset from 0pF. It is possible to describe this curve with a polynomial equation, but a third-order polynomial is needed to get good accuracy. This is of the form $C(\text{pF}) = af^3 + bf^2 + cf + d$ ($d = 0$).

The first cubed term (f^3) results in huge numbers, well beyond 32-bit integer calculations. There are ways of getting around this by cleverly sequencing the calculations, but I chose a simpler method. There is not much of a curve between individual calibration points, and a linear interpolation gives acceptable accuracy.

Capacitance readings are taken continuously at about half-second intervals. The resolution is 0.1pF for values below 200pF. Above this, only the integral part of the value is shown, as the fraction is unlikely to have significant accuracy.

Inductance measurements

Inductance measurements are made a bit differently. We don't have the privilege of built-in calibration inductors, as any accurate types would have to be air-cored and far too large.

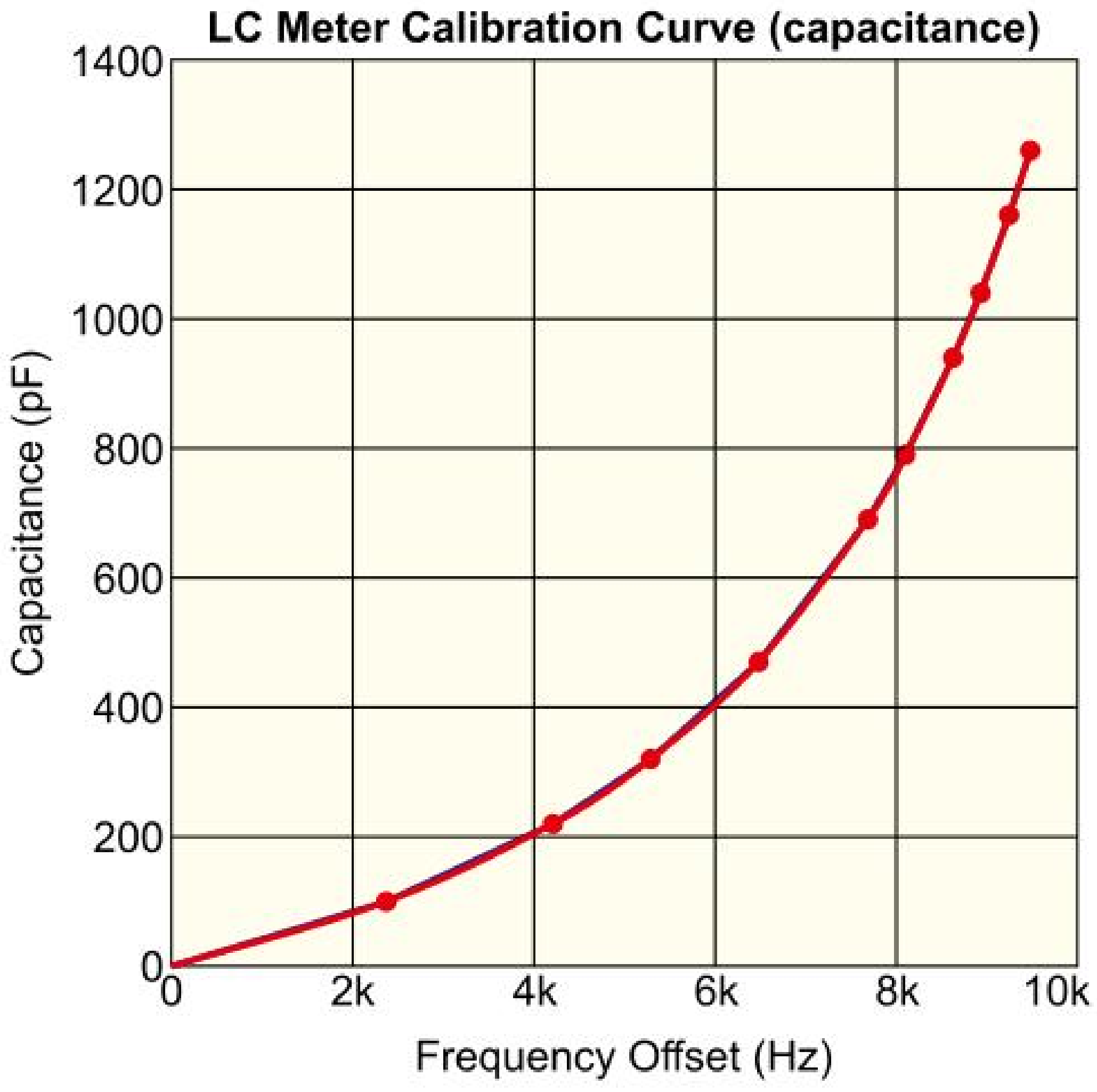


Fig.2: plot of oscillator frequency shift vs external capacitance. Reading a frequency shift off this plot will tell you the connected capacitor value. This can be accurately approximated with a third-order polynomial, but linear interpolation between the points shown is close enough for our needs.

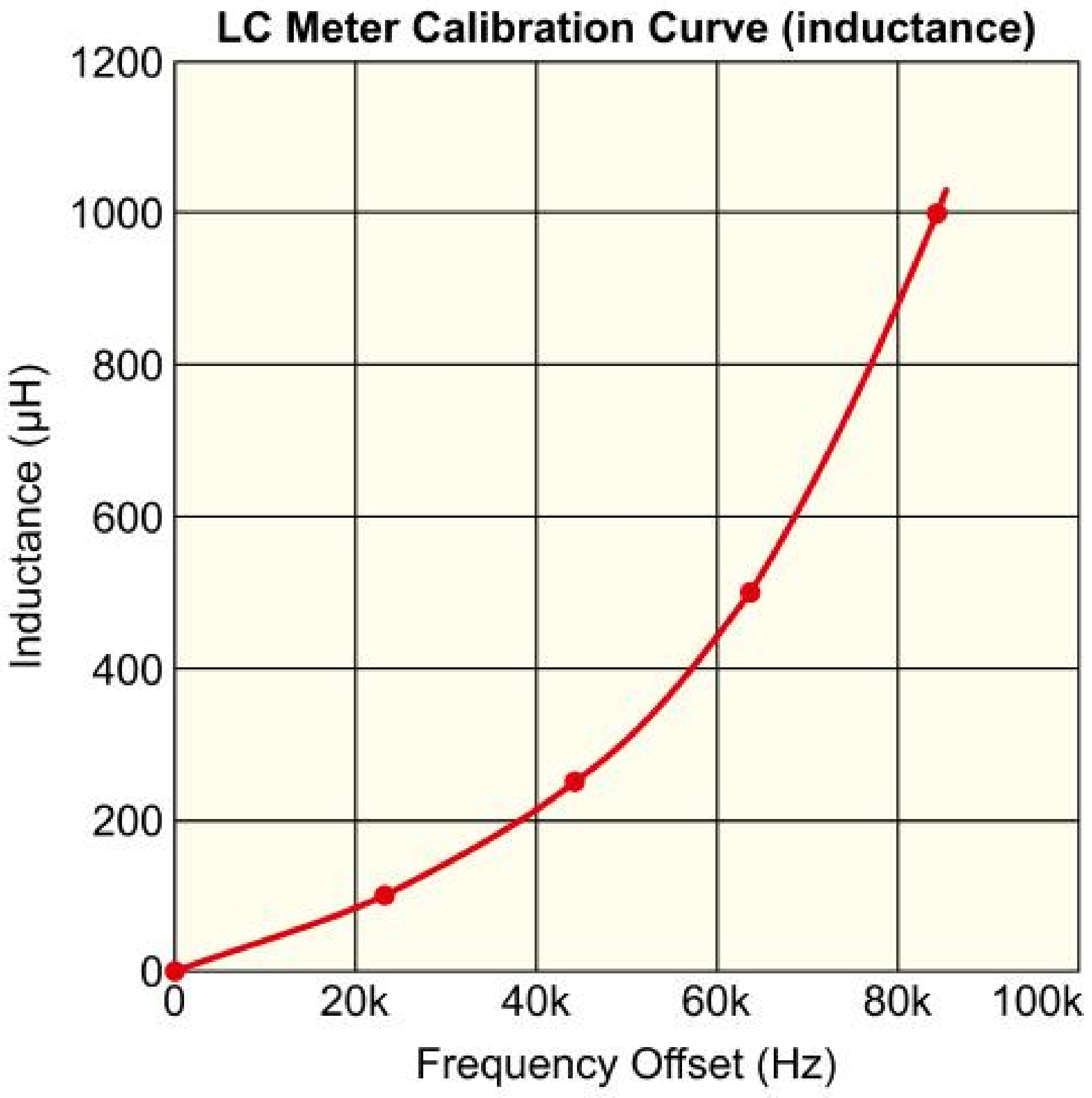


Fig.3: the inductance vs frequency shift curve is similar to the capacitance curve shown in Fig.2, but it needs second-order curves over most of its segments to give a good enough approximation. The exception is the 0-10µH section, which is close enough to being linear.

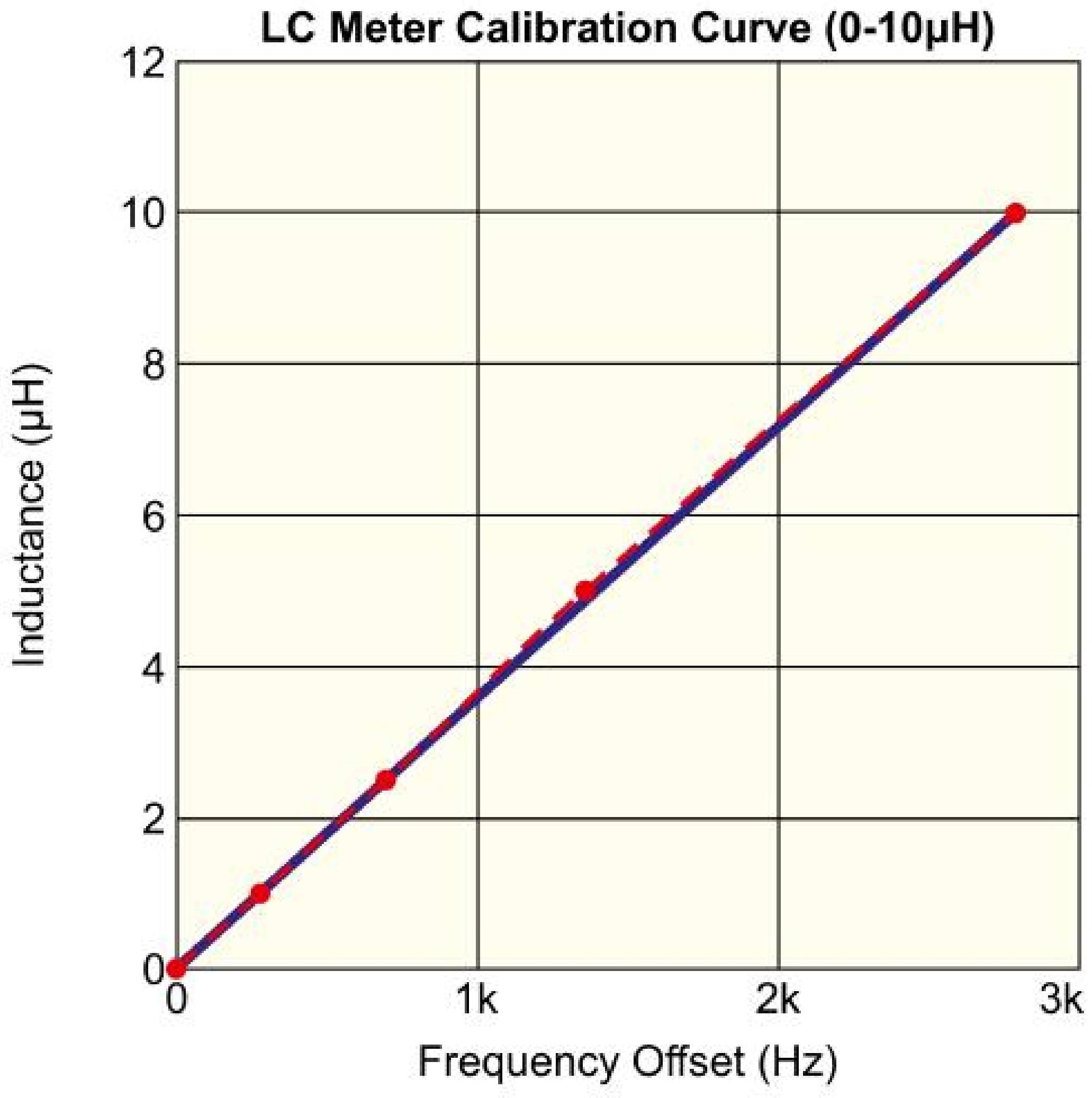


Fig.4: a close-up of the 0-10µH section of Fig.3, comparing the actual curve to a linear approximation. The resulting errors are minor in comparison to other sources of uncertainty.

I measured the oscillator frequency with each of the calibration inductors that came with my Meguro Q-Meter, up to 2500µH, which is close to the practical limit of the *LC Meter*. This gave me a calibration curve similar to the one used for capacitance. This curve may also be approximated by a third-order polynomial $L = 20^{-12} f^3 - 50^{-8} f^2 + 0.0045 f$. With C in pF, L in µH and f in MHz

Again, this makes 32-bit integer computation difficult, so I split it into several segments, some approximated by quadratics, as shown in Fig.3. I've included a spreadsheet in the download package for this project with the relevant calculations, all available from the November 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**

The 0-10µH section of the curve is so close to a straight line that a linear equation is very accurate (Fig.4). From this, we can estimate the likely resolution for low inductance values. To get the required resolution, the oscillator must be stable in the measurement period of four seconds. The measurement readout is stable in practice, with the 10nH digit remaining constant between measurements.

Note that this calibration curve depends on the actual inductance value of inductor L1, so we have to correct the difference. This requires a measure of the value of L1, which is performed as described in the 'Onboard inductor value calculation' panel.

By comparing the measured value with the one I used in my prototype, the offset frequency readings are modified for better accuracy.

Firmware

The firmware is written in BASCOM (BASIC for AVRs), which is easy to implement and easy to follow. It occupies just over half of the 32KB flash memory on the ATmega328 processor. If you want to know more about it, download and check the source code.

Case preparation

The recommended enclosure is from Ritec (Altronics Cat H0324) and includes a clear lid. It has a slightly indented clear window measuring 98 × 76 mm. The drilling measurements shown in Fig.5 relate to this window.

The transparent top is relatively brittle, so be careful if using a centre punch as it can crack the plastic. Likewise, use a low-speed drill to prevent damage to the top. A step drill gives the cleanest and most accurate results.

As these holes have to be very accurate, first locate the bottom-left hole 16mm from the window edges. Drill this to 3mm and attach the blank PCB with an M3 screw and nut. Position the PCB to be precisely square, then drill the other holes in the middle of the switches. Alternatively, use Fig.5 as a template to mark the four holes that need to be drilled, then enlarge the holes to 6.35mm (¼in) or 6.5mm.

The window has a moulding 'bump' in the centre that interferes with the OLED behind it. Drill this out as well, to 6.35mm or 6.5mm.

Construction

The *LC Meter* is built on a 91.5 × 63.5mm double-sided PCB coded CSE220503C, available from the *PE PCB Service*. Components are mounted on both sides of the board, with the connectors and Arduino Nano module on the back, as shown in the overlay diagrams, Figs.6 and 7.

The only fine-pitch SMD is the MPC1661 up-converter. It is a five-pin device, so the orientation is obvious. Solder it first, followed by the other ICs. Add a thin layer of flux paste onto its pads before placing it, tack one pin and then check carefully that the other pins are correctly aligned, ideally using a magnifier. If necessary, re-heat the tacked joint and nudge it into position. Then solder the other pins.

Clean the flux off the board and inspect REG1 to verify that all its pins are soldered properly and none are bridged. If there are bridges, add a bit flux paste and then remove them with a piece of solder wick.

The remaining 14-pin and 16-pin chips are relatively easy to solder but make sure they are oriented correctly. Follow with the five transistors, four BJTs (Q1-Q4) and one MOSFET (Q5). They are all in three-pin SOT-23 packages, so don't get them mixed up.

The diodes are in two different package types: plastic SOT-123 (ZD1 and D4) and cylindrical glass Mini-MELF (D2, D5). In each case, start by identifying the striped (cathode) end. You might need a magnifier to see the stripe on ZD1 and D4. Then solder them in place, as shown in Fig.6.

Now fit all the discrete resistors and capacitors. They are all M2012/0805 (2 × 1.2mm) or M3216/1206 (3.2 × 1.6mm) size, and none are polarised, but the resistors should have their codes marked on top. After that, solder the small SMD relay, taking care to orient it correctly. That's the last SMD.

Now add the through-hole components, starting with the lowest-profile axial devices and working your way up. The OLED screen plugs into a 4-pin socket strip. Carefully slide off the plastic on the OLED pins to reduce the height above the board. It is then secured by two M2.5 or M2 screws with 8mm untapped spacers.

The Arduino Nano and connectors are on the opposite side of the board. I also used socket strips for the Nano, but that is optional. The Nano has 15 pins on each side, so ideally, you'd use 15-pin strips, but they are not easy to find. You can use 14-pin headers inserted towards the top edge of the board, as the lowest pin on each side is not electrically connected, or cut down longer sockets.

The other components on the back of the board are headers CON2 and CON4, the optional debugging header (CON3) and the BNC socket (CON1).

All the switches mount on the front, and are best fitted last. We've specified solder-lug switches rather than PCB-mounting types, and provided

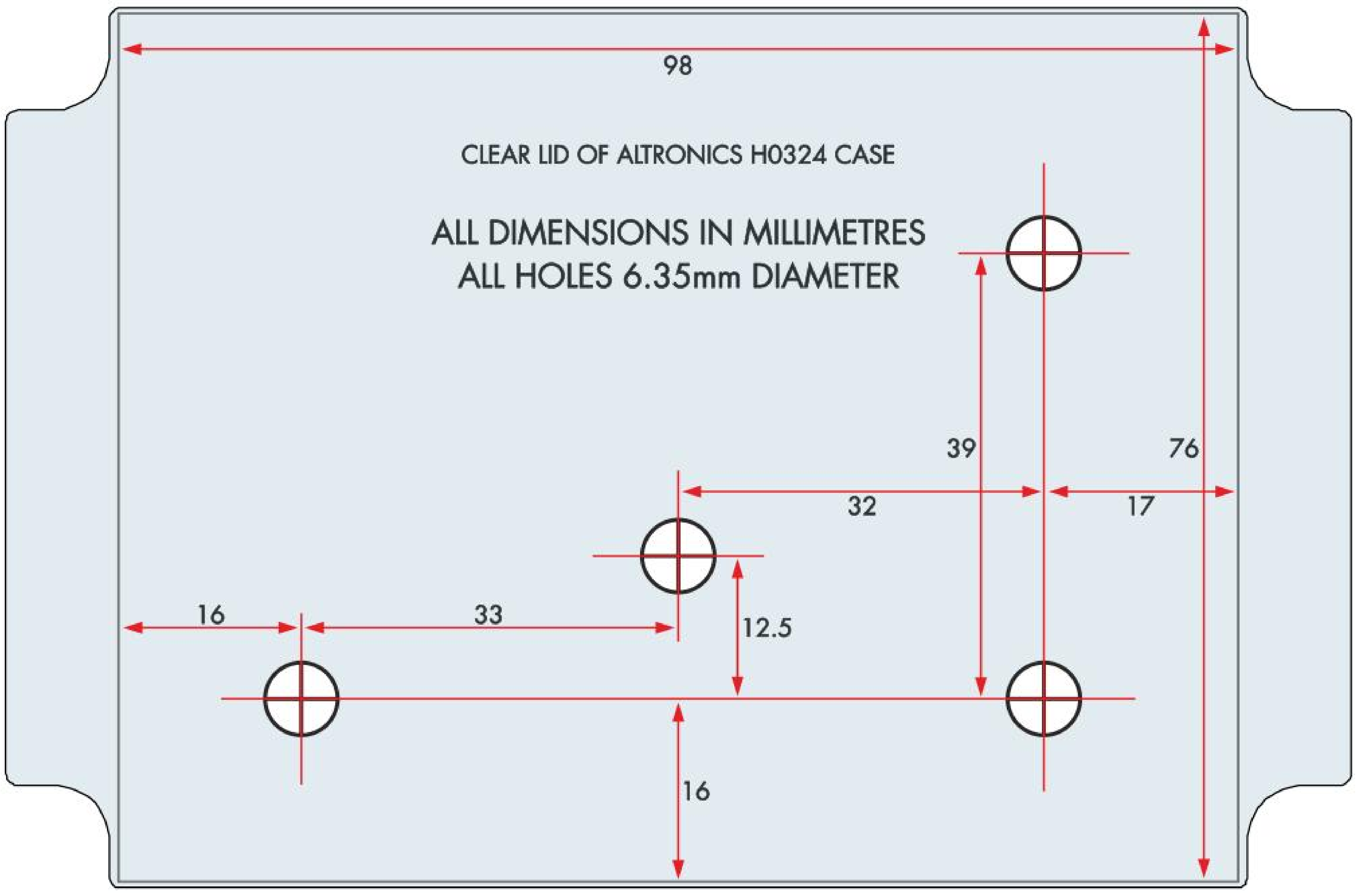

98
CLEAR LID OF ALTRONICS H0324 CASE
ALL DIMENSIONS IN MILLIMETRES
ALL HOLES 6.35mm DIAMETER
39
76
32
17
16
33
12.5
16

Fig.5: the locations of the holes in the clear lid of the H0324 plastic box. Download it from the November 2023 page of the PE website at: https://bit.ly/pe-downloads (and print it out at actual size) and use it as a template. See the comment at the end of the body text explaining that one hole and switch could be omitted.

Onboard inductor value calculation

Since the value of inductor L1 will vary with the test frequency due to the permeability of the ferrite core varying, we cannot rely on its nominal value. To get a good estimate of the inductance in the oscillator circuit, we need to make some calculations. The capacitance across it is the 220pF plus the stray capacitance; call this C1. We know that $\mathbf{L = 1 / (\omega_1^2 \times C_1)}$, where $\omega = 2\pi f$ (f = oscillator frequency).

The resonant frequency will change if we add a capacitance C2 in parallel with C1. As long as it is not too different from the original frequency, the inductance value will be close enough to the same. The new equation becomes:

$$\mathbf{L = 1 / (\omega_2^2 \times [C_1 + C_2])}$$

Combining the above two equations, we get: $\mathbf{\omega_2^2 \times (C_1 + C_2) = \omega_1^2 \times C_1}$

This can be rearranged to: $\mathbf{(C_1 + C_2) / C1 = \omega_1^2 / \omega_2^2}$

Further manipulation gives us: $\mathbf{C_1 = C_2 / (\omega_1^2 / \omega_2^2 - 1)}$

As the 2π factors in ω_1 and ω_2 cancel out, this becomes:

$$\mathbf{C_1 = C_2 / ([f_1 / f_2]^2 - 1)}$$

To more easily calculate this using 32-bit integer arithmetic, we multiply the numerator and denominator on the right-hand side by f_2^2 to give the equivalent equation: $\mathbf{C_1 = (f_2^2 \times C_2) / (f_1^2 - f_2^2)}$

In our case, we know the added capacitance C_2, and measuring f_1 and f_2 gives us the value of C_1. From this, we can calculate L according to the first equation above, or the simpler version, $\mathbf{L = 25330 / (f^2 \times C)}$ mentioned in the body text.

This calculation is done during the calibration on power-up, with C_2 being the 100pF calibration capacitor. The fact that the frequencies measured are divisions of the actual frequencies does not matter as the ratio remains constant.

sufficiently large slots to solder in the lugs. This is because the solder lug style switches are more widely available, especially in the wide variety needed here. Make sure they're perpendicular to the board before soldering all the lugs.

Clean the board with circuit board cleaner and inspect all the soldered joints for any that may have been missed, and check for shorts between pins. Finally, place the jumper on JP1 in the position shown in Fig.6.

Assembling it into the case

Presumably, you followed the earlier instructions to prepare the lid with the aid of the blank PCB. If not, you'll have to go back and use a template made from Fig.5 instead. Then you can print and prepare the front panel label, shown in Fig.8.

Print this label on photographic paper. I placed a transparent 1mm-thick sheet of polycarbonate on top of the label to protect it, but you could laminate it instead. Although the PCB has mounting holes, the toggle switches are adequate to bolt the unit onto the panel.

The battery holder for the three AA cells (BAT1) should be attached to the bottom of the case with double-sided adhesive tape. While you could solder its leads directly to the PCB pads for CON2, that would make disassembly somewhat tricky. So we've specified a polarised header for CON2 and a matching plug. Crimp and/or solder the plug to the battery leads, ensuring they are not reversed.

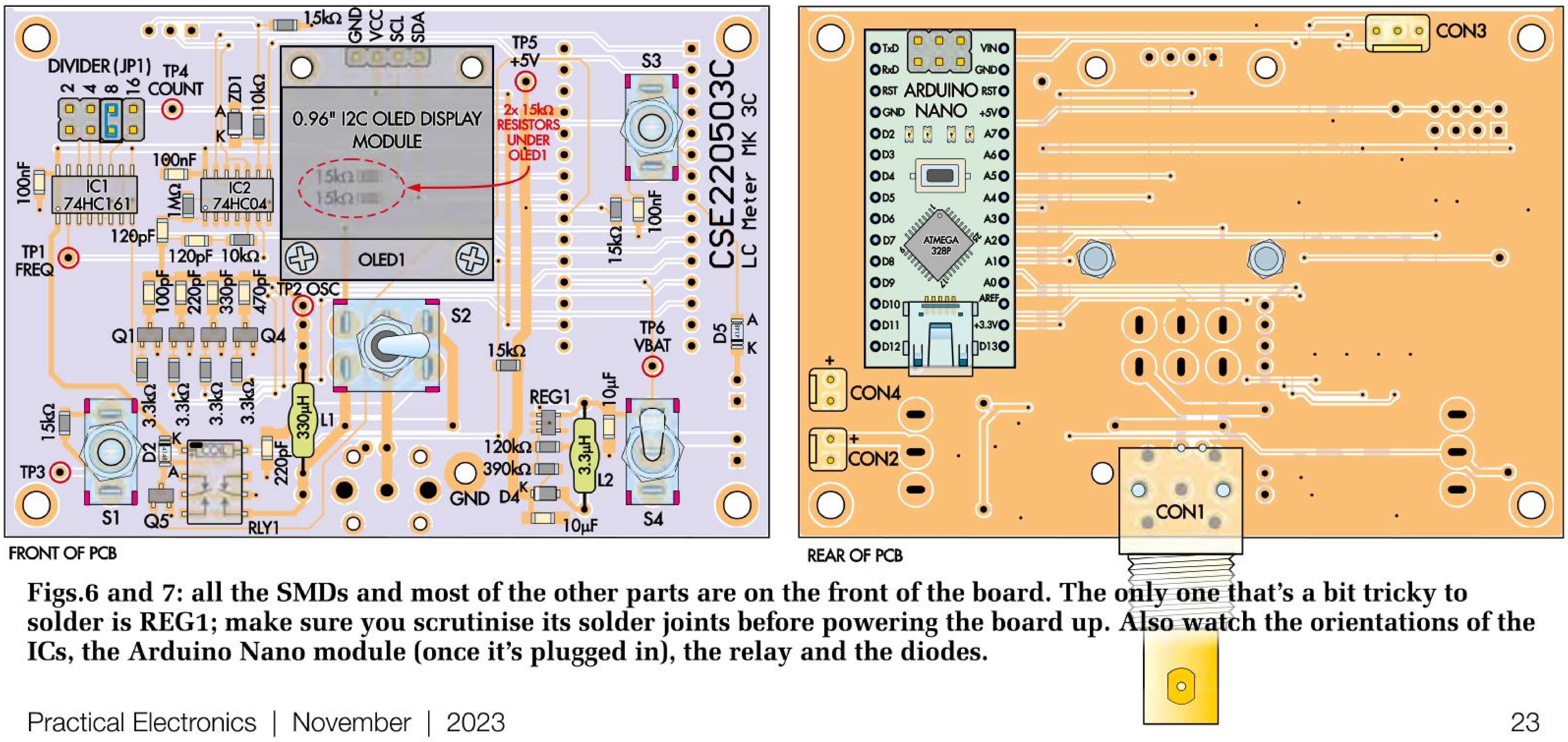
Before plugging the battery in, carefully check that polarity as the PCB doesn't have reverse polarity protection.

Using it

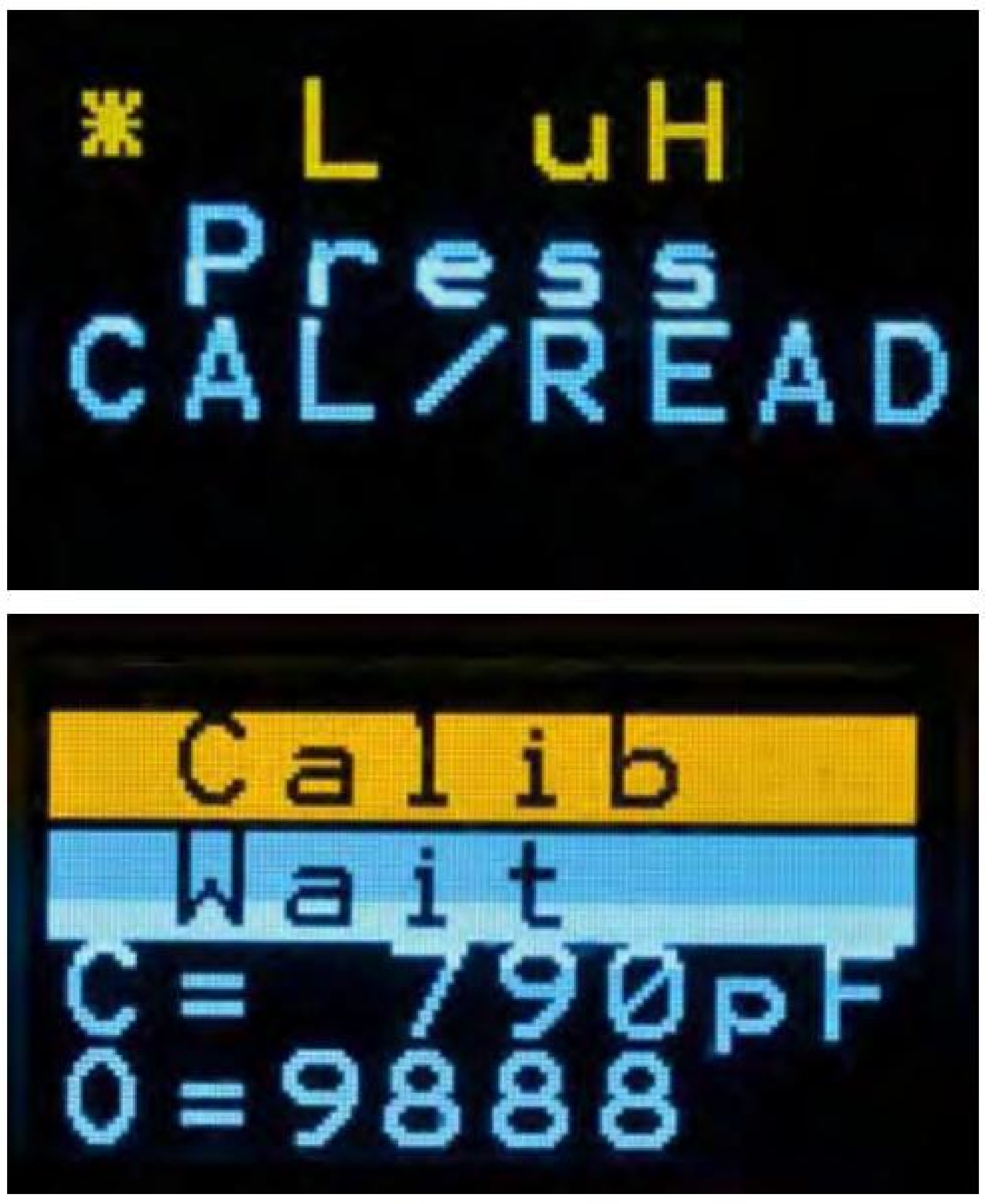
The BNC connector by itself is not ideal for connecting to separate components. The simplest solution is to use a BNC plug with screw terminals and a couple of clip leads to connect to leaded components. You can connect some parts directly to the screw terminal. With care, the clip leads may also connect to M3216/1206- and M2012/0805-size SMDs.

Depending on the length of leads, these will add about 100nH to measured inductances. This can be measured by

The battery holder and piezo buzzer are located in the case so that they don't interfere with the PCB when the lid is attached. Note the position of the hole in the side for the BNC socket.


FRONT OF PCB
DIVIDER (JP1)
2 4 8 16
TP4 COUNT
ZD1
A
K
10kΩ
1.5kΩ
GND VCC SCL SDA
0.96" I2C OLED DISPLAY MODULE
15kΩ
15kΩ
OLED1
TP5 +5V
2x 1.5kΩ RESISTORS UNDER OLED1
S3
CSE220503C
LC Meter MK 3C
100nF
IC1 74HC161
100nF
IC2 74HC04
1MΩ
120pF
TP1 FREQ
120pF
10kΩ
100pF
220pF
330pF
470pF
TP2 OSC
Q1
Q4
S2
15kΩ
100nF
15kΩ
TP6 VBAT
D5
15kΩ
3.3kΩ
3.3kΩ
3.3kΩ
3.3kΩ
330µH
L1
REG1
10µF
D2
TP3
S1
Q5
RLY1
220pF
120kΩ
390kΩ
GND
D4
3.3µH
L2
10µF
S4
REAR OF PCB
TxD
RxD
RST
GND
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
VIN
GND
RST
+5V
A7
A6
A5
A4
A3
A2
A1
A0
AREF
+3.3V
D13
ARDUINO NANO
ATMEGA 328P
CON3
CON4
CON2
+
CON1

Figs.6 and 7: all the SMDs and most of the other parts are on the front of the board. The only one that's a bit tricky to solder is REG1; make sure you scrutinise its solder joints before powering the board up. Also watch the orientations of the ICs, the Arduino Nano module (once it's plugged in), the relay and the diodes.



* L uH
Press
CAL/READ

Calib
Wait
C= 790pF
O=9888

Some example screengrabs when operating the LC Meter Mk3.

shorting the leads together; then, you can subtract this from the inductance reading. That will only be necessary for values below about 5µH.

An alternative is a small PCB I designed (coded CSE200603) connected by a short coax cable, BNC to SMA – see the end of the parts list. This allows more device options and includes pads for SMD capacitors. M3216 and M2012 chip capacitors can be accurately measured by carefully holding them down on the pads with a non-conducting stylus.

The added capacitance of the coax cable is about 15pF, so you need to run calibration with the adaptor connected, cancelling it out. Calibration runs automatically at power-up, but it can also be triggered manually by pressing the CAL/START switch. This requires the L/C switch to be in the C position and no external component connected.

To make inductance measurements, switch to the L position, connect the unknown coil and press CAL/START. This will power relay RLY1 for two seconds to give a reference zero offset.

After that, RLY1 is switched off, placing the unknown in series with L1. A lower frequency will be measured and subtracted from the 'zero' point to give an offset frequency. The inductance is then calculated from this offset. The inductance will continue to be measured from then on, each reading taking about four seconds.

If no inductor is connected, the display will show 'Reading Error'. In any case, it's best to take several readings to get a consistent result. The calibration is accurate up to 2,500µH (2.5mH). It will measure values higher than that, but the precision of such readings is unknown.

Future enhancements

The onboard three-position toggle switch (S1) provides Option 1 and Option 2 for possible enhancements in the future. One option I tried was to double the measurement window for improved resolution but, in practice, there was no significant difference, so I discarded it. That switch may be omitted to reduce the construction cost slightly, and the label modified to remove the options.

Finally, I would like to acknowledge Andrew Woodfield for his helpful suggestions. It was largely his desire for measuring sub-1µH inductors that I was pressed to improve my earlier designs.

Parts List – LC Meter Mk3

1 double-sided PCB coded CSE220503C, 91.5 × 63.5mm
1 125 × 85 × 55mm IP65 sealed ABS enclosure (clear lid) **[Altronics H0324]**
1 panel label, 98 × 76mm
1 Arduino Nano microcontroller board (MOD1)
1 0.96-inch OLED display module with I^2C interface and SSD1306 controller (OLED1) **[SC6176 (cyan)]**
1 Omron G6K-2F-Y-DC5V SMD relay (RLY1)
1 330µH axial RF inductor (L1)
1 3.3µH axial RF inductor (L2)
1 PCB-mount miniature SPDT centre-off toggle switch (S1)
[Altronics S1330; S1332 is PCB-mounting equivalent]
1 PCB-mount miniature DPDT on-on toggle switch (S2)
[Altronics S1345; S1350 is PCB-mounting equivalent]
1 PCB-mount miniature SPDT centre-off momentary toggle switch (S3)
[Altronics S1340; S1333 is PCB-mounting equivalent]
1 PCB-mount miniature SPDT on-on toggle switch (S4)
[Altronics S1310; S1315 is PCB-mounting equivalent]
1 PCB-mount right-angle BNC connector (CON1) **[Altronics P0529]**
2 2-way polarised vertical pin headers with matching plugs (CON2, CON4)
1 3-way polarised vertical pin header (CON3; **optional**, for debugging)
1 4-way header socket (for OLED)
2 14-pin or 15-pin header sockets (**optional**, for mounting Nano)
1 2×4-pin header, 2.54mm pitch (JP1)
1 jumper shunt (JP1)
2 8mm untapped spacers (for mounting OLED)
2 M2 × 12-16mm panhead machine screws and nuts (for mounting OLED)
1 3 x AA battery holder with flying leads (BAT1)
3 AA cells (ideally alkaline)
1 200mm length of foam-core double-sided tape (to attach battery holder)
1 BNC to screw terminal adaptor (**optional**, to measure components)
1 chassis-mount piezo buzzer (**optional**) **[Altronics S6109, Jaycar AB3462]**

Semiconductors
1 74HC161D or 74AC161D synchronous binary counter, SOIC-16 (IC1)
1 74HC04D or 74AC04D hex inverter, SOIC-14 (IC2)
1 MCP1661T-E/OT integrated high-voltage boost regulator (or MP1541DJ-LF-P boost converter), SOT-23-5 (REG1)
4 BFR92P low-capacitance NPN transistors, SOT-23 (Q1-Q4)
1 2N7002 60V 115mA N-channel MOSFET, SOT-23 (Q5)
1 BZT52C4V7 4.7V 500mW zener diode, SOD-123 (ZD1; **optional**)
2 LL4148 75V 500mA small signal diodes, SOD-80 (D2, D5)
1 MBR0540 50V 500mA schottky diode, SOD-123 (D4)

Capacitors *(all SMD M2012/0805 ceramic)*
2 10µF 16V X5R
1 470pF 50V NP0/C0G 1%
1 330pF 50V NP0/C0G 1%
2 220pF 50V NP0/C0G 1%
2 120pF 50V NP0/C0G 5%
1 100pF 50V NP0/C0G 1%
3 100nF 50V X7R

Resistors *(all SMD M2012/0805 1%)*
1 1MΩ
6 15kΩ
1 390kΩ
2 10kΩ
1 120kΩ
4 3.3kΩ

Optional Adaptor Board
1 double-sided PCB coded CSE200603, 33 × 20.5mm
1 SMA edge connector
1 6-pin header socket
1 short SMA to BNC cable

0805
1206
GND
CSE200603

This optional adaptor board makes it easier to test components.

DC SUPPLY FILTER FOR VEHICLES

by John Clarke

INPUT
OUTPUT
LED1
DC SUPPLY FILTER
SILICON CHIP
08108221
© 2022
REV.A
100nF
100µF
100nF
TVS1
100nF

- Handles 12V @ 5A (or 10A with alternative inductors)
- Easy to build and store in a compact UB5 Jiffy box
- Effective noise and transient suppression
- Low standby current under 5mA
- Transient voltage clamping
- Low-pass filtering
- Fused supply

Many devices will run off 12V DC, so it's pretty tempting just to plug them into a vehicle supply (via a cigarette lighter socket or similar), and away you go. But you're likely to run into two significant problems with that: supply noise messing with the device's performance and voltage spikes possibly frying it. This *DC Supply Filter* solves both those problems.

Protect your 12V equipment from voltage transients that could cause irreparable damage using this *Vehicle DC Supply Filter*. It connects inline with the DC supply to clamp and filter transient voltage excursions. It's especially useful for audio gear as it reduces that horrible ignition system whine that can pass through the vehicle's electrical system.

While many 12V supplies are transient and noise-free, some are not. That's especially true of the 12V (or 24V) supply from a vehicle with the engine running. In particular, heavy load switching such as electric radiator fans or air conditioner compressors switching on or off can produce voltage transients on top of the theoretically smooth 12V DC supply.

Other noise and transient sources include the vehicle's alternator, where alternator brushes produce electrical noise, and the ignition system with frequent pulses delivered to the coils and spark plugs.

It isn't just for vehicles, either. Mains switchmode power supplies can also have transients on their output, as well as noise. These typically have high-frequency noise due to the switching nature of the supply and can produce transients when the load is abruptly changed from full load to a lesser current.

We have found on multiple occasions that modern switchmode plugpacks are unsuitable for powering sensitive circuits, including signal generators, instrumentation, audio preamplifiers and theremins.

While some equipment powered from such sources can survive damage, others are more sensitive. The device may fail quickly due to voltage transients exceeding the internal electronics ratings, or it could fail over an extended period as sensitive electronic components accumulate damage with each voltage transient.

Transients and noise can be reduced with a low-pass filter, and a transient voltage suppressor can absorb harmful spikes. The filter effectively removes high-frequency signals from the DC supply. The result is a supply with much lower noise, less high-frequency ripple and more minor voltage transients. Filtering can go a long way to protecting your valuable equipment from damage.

Our *DC Supply Filter (hereon, 'Filter')* is quite compact and can be housed in a small Jiffy box. Heavy-duty screw terminals are provided for the input and output connections, plus there is an onboard fuse and a power-on indicator LED.

Filter design

The circuitry for the *Filter* is relatively straightforward, as shown in Fig.1. It uses two inductors and several capacitors. A transient voltage suppressor (TVS) is included to absorb excessive voltage spikes.

The TVS specified begins to conduct at its V_{BR} (reverse breakdown voltage) of 14.4V and provides full voltage clamping at 23.5V, although it would have to be a mighty spike for it to allow the voltage to rise much above 16V.

Note that a TVS will conduct a small leakage current at voltages below its reverse breakdown voltage. As it turns out, about half the quiescent current of this *Filter* is due to the TVS. But we need it to protect the downstream equipment from the worst spikes such as 'load dumps'.

If you want to use the *Filter* at a higher voltage, like 24V, you will need to change the TVS to one with a suitable V_{BR} rating, plus the two electrolytic capacitor working voltages will

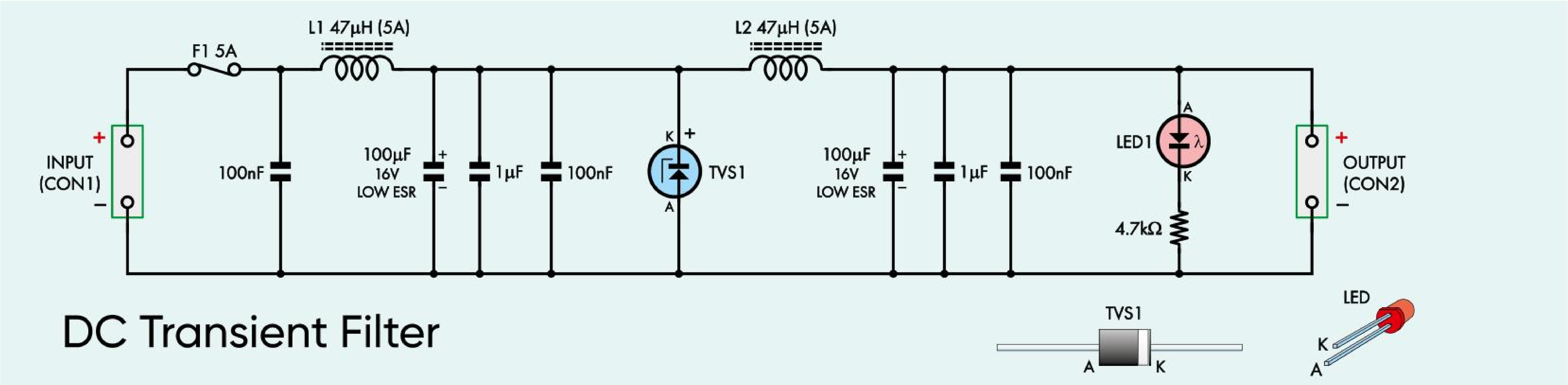


Fig.1: the Filter has two main roles: to reduce high-frequency noise and absorb large spikes. Noise is attenuated by two cascaded LC filters (47µH/101.1µF) while the TVS between the two shunts to ground any particularly large voltage spikes that make it past the first filter stage.

need to be increased (to 35V or 50V for a 24V supply).

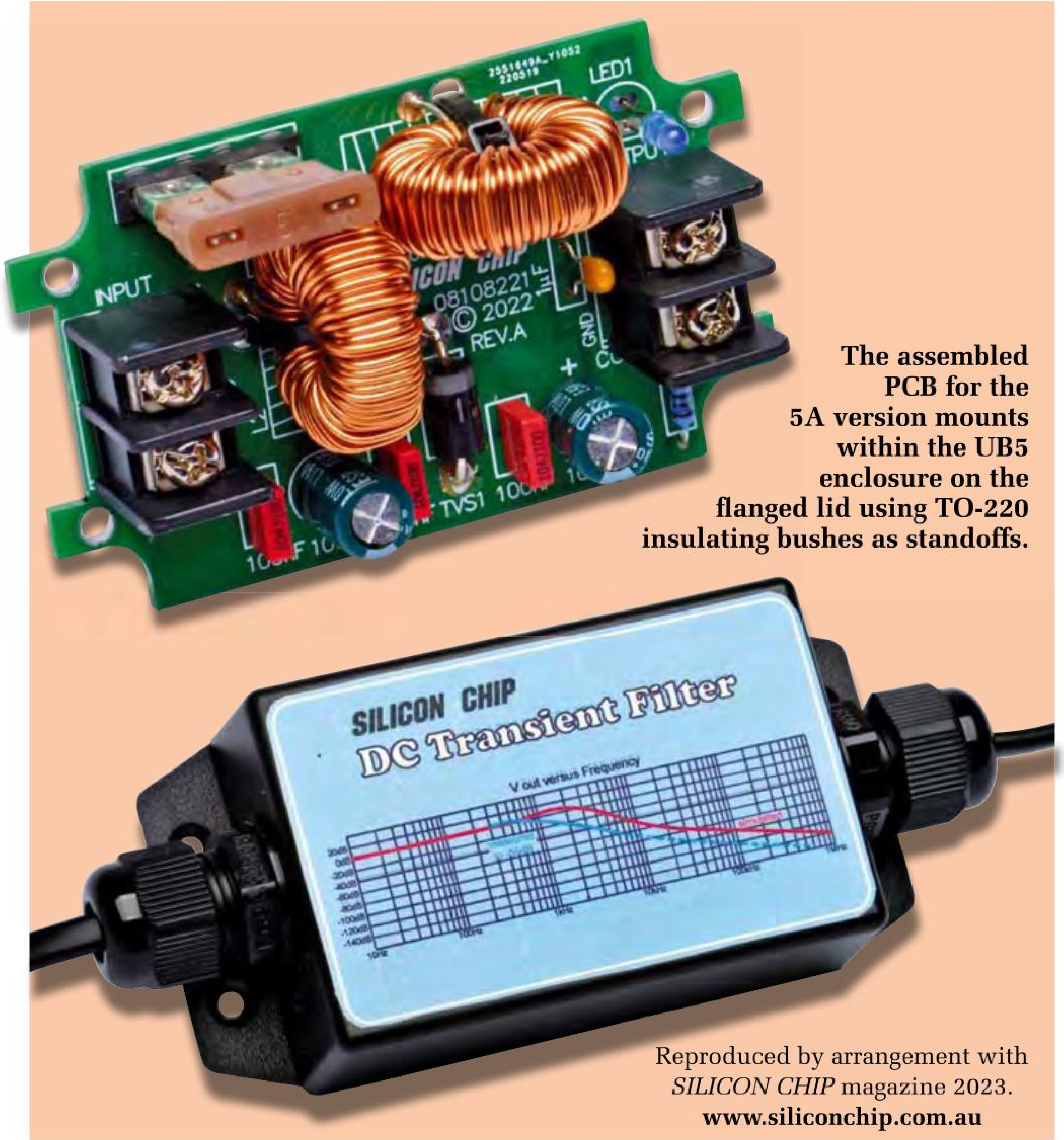
For the particular TVS we used, we measured a leakage current of about 2.6mA from 12V up to 15.6V, at which point the current increases as it begins to clamp the voltage. The leakage current through the TVS is something to consider if this is going to be the cause of battery discharge over time.

An extra 2mA (approximately) is drawn by the power indicator LED. Typically, when used on a vehicle supply, the overall 4.6mA current should not discharge the battery except over a long time.

Returning to the Fig.1 circuit, power is applied at CON1, and current flows through the fuse (F1) to a small bypass capacitor, then the inductor L1, rated at 47µH and 5A. Following this are three paralleled capacitors: a 100µF low-ESR electrolytic, 1µF multi-layer ceramic and 100nF MKT polyester. These bypass ripple, noise and transients to ground.

The TVS is connected in parallel with these capacitors to clamp over-voltage spikes.

We use a mix of capacitors to improve the filtering action over a wide range of frequencies. The non-electrolytic capacitors function better at higher frequencies, while the electrolytic capacitor provides reasonable filtering below 100kHz and better still below 10kHz.



The assembled PCB for the 5A version mounts within the UB5 enclosure on the flanged lid using TO-220 insulating bushes as standoffs.

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A second identical LC (inductor/capacitor) low-pass filter follows, forming a second stage to reduce noise and ripple going to the output at CON2.

Note that a radio signal filter design would likely not include the capacitors across CON2 because they expect 50Ω source and load impedances. With our *Filter*, we expect the source impedance will be close to 0Ω, and the output impedance can be anywhere from about 1kΩ down to as low as 2.9Ω for a 5A load with a 14.4V supply.

The capacitance across the output of the *Filter* at CON2 gives an effective frequency roll-off that is relatively independent of the external load connected to the output. In effect, the capacitors provide a low impedance down to below 10Hz.

The LED indicator (LED1) is driven from the 12V supply via a 4.7kΩ resistor. The LED does not light if the unit is not powered or the fuse has blown.

Testing the Filter

We conducted a test to see how effectively the Filter *Filter* voltage transients using two power supplies. One supply was set to provide 14.4V DC and the other 50V DC. The 14.4V was fed to the filter input via a large inductor to isolate this from the transient voltage derived from the 50V supply.

In order to create a suitable test transient, we charged up a 100nF 100V capacitor that was subsequently switched over to connect to the *Filter* input momentarily.

The result can be seen in Scope 1. The top yellow trace shows the input voltage transient with a peak 26.4V above the steady 14.4V DC supply. At the output of the *Filter*, shown on the lower cyan trace, there was only a 600mV increase; that's a reduction in transient amplitude by a factor of 44 times.

Note that the oscilloscope traces were AC-coupled, so the 14.4V DC applied to the *Filter* is not seen on the oscilloscope traces. If we had DC

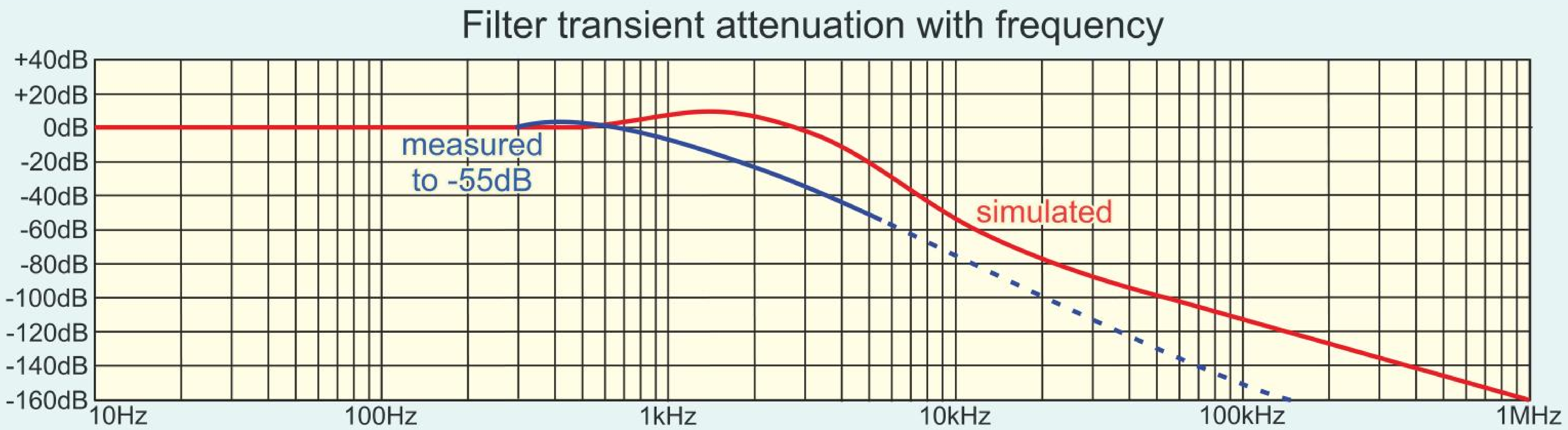
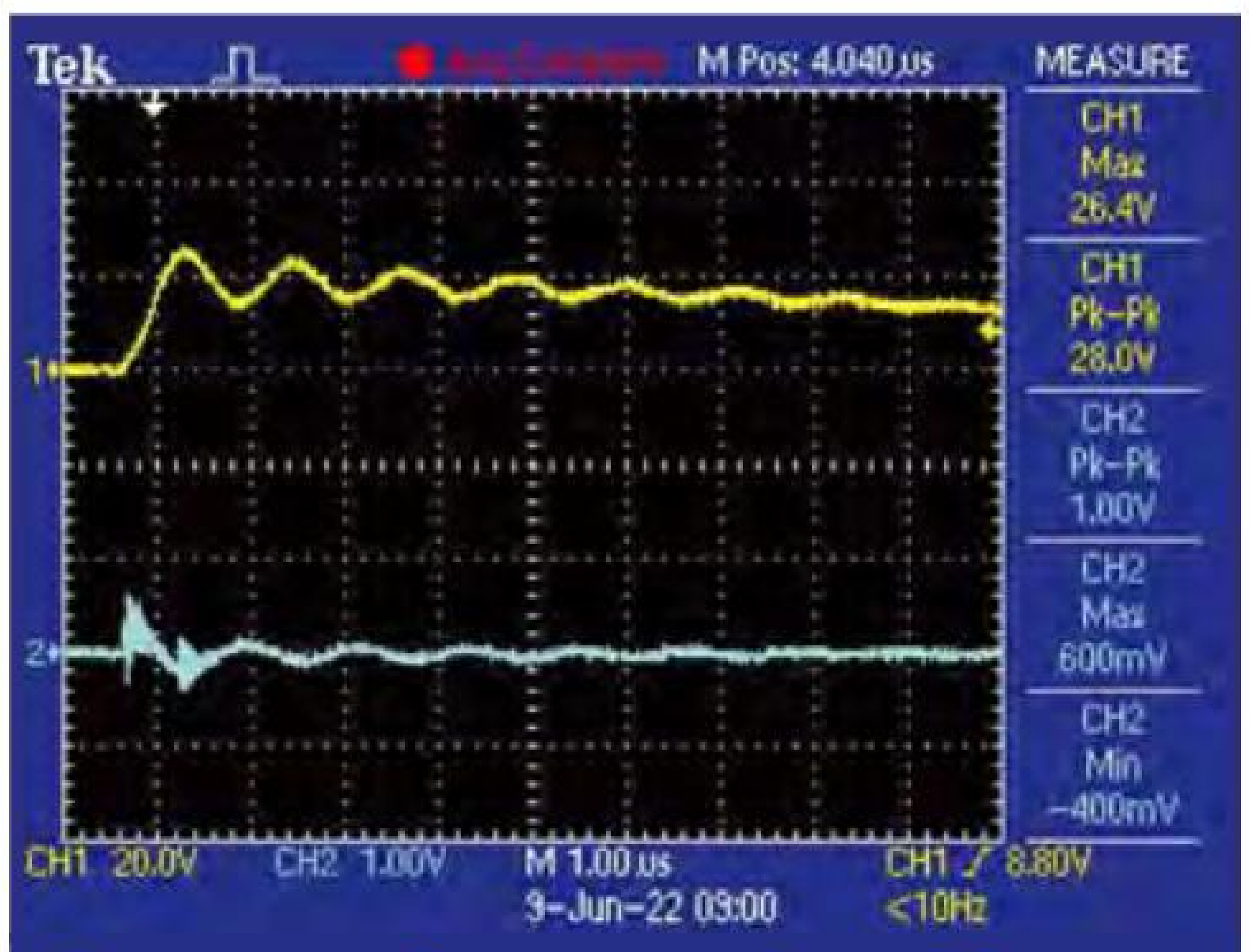


Fig.2: the measured performance of the prototype is quite a bit better than what was predicted by simulation, with noise and ripple attenuation starting below 1kHz and already below –20dB by 2kHz. –55dB is reached just above 5kHz.



Scope 1: a demonstration of the effectiveness of the Filter. We purposefully created a 26V spike on top of a 12V supply, causing some ongoing oscillations at the Filter's input. The voltage at the Filter's output peaked at only 0.6V above the DC level.

coupled the traces, the sensitivity (volts per division) would have needed to be much higher to prevent the traces from going off-screen at the top. That would have made the details of the transient harder to see.

We also plotted the *Filter's* frequency response using the LTspice simulator and by measurement in Fig.2. The measurement was checked down to –55dB at 6kHz, and the expected roll-off above this frequency continues as an extrapolation of the measured roll-off rate.

Construction

The *Filter* is built on a double-sided, plated-through PCB, coded 08108221 , measuring 77 × 46mm and available from the *PE PCB Service*. The 5A version fits in a standard UB5 plastic Jiffy box.

If you wish to make a 10A version, you will need a larger UB3 box. The part changes required are shown in the parts list, including the use of a 10A fuse instead of 5A. See the separate panel on winding and mounting the inductors.

Refer to the overlay diagram, Fig.3, as a guide to construction.

Begin by soldering the 4.7kΩ resistor and low-profile parts such as the TVS and capacitors. The TVS needs to be oriented correctly, with the striped end to the top. The two electrolytic capacitors must have their striped (negative) side toward the bottom, with the longer positive leads to the pads marked with a plus sign on the PCB, towards the top.

The fuse holder, CON1 and CON2 can be fitted now. Inductors L1 and L2 are installed upright, with the leads entering the smaller holes adjacent to each side of the inductors on the PCB.

The cores are held using a cable tie through each core and around under the PCB via the larger holes. Ensure the cable tie joint is on the top side of the PCB rather than on the underside, as the PCB needs to sit low in the Jiffy box to fit.

Depending on your preference, the LED should be installed either down close to the PCB or with long enough leads to protrude through the enclosure.

Mounting it in the enclosure

If using the UB5 Jiffy box, mount the PCB to the inside of the flanged lid using countersunk head screws from the outside, with the PCB raised off the base with insulating bushes. These are the type usually used to isolate a TO-220 transistor (or similar) from its mounting screw.

Cut a section of the round washer portion of the bush with side cutters to allow it to fit on the flanged lid, adjacent to the corner mount mouldings, as shown in the photo at the bottom of the next page.

Holes at each end of the enclosure are required for the cable glands. The PCB has cut-outs to make room for the gland nuts, so ensure the holes are centred on the enclosure sides. The input and output wires pass through the cable glands at each end and are terminated at the screw terminals. Make sure the wiring polarity is correct, as the fuse will blow if connected incorrectly to the input.

Draw the wires out through the glands as the PCB is inserted into

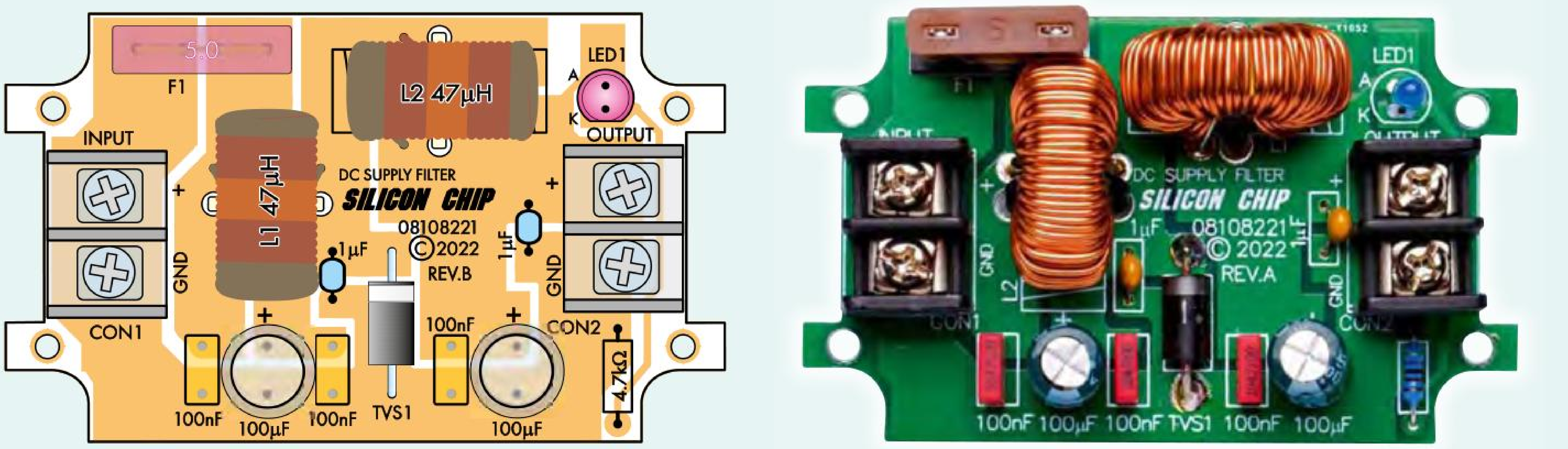


Fig.3: the Filter assembly is straightforward; the components shown here are for the 5A version. Only the TVS, LED and electrolytic capacitors are polarised. For the 10A version, the inductors will be larger and must be mounted above the other components on longer leads.

the enclosure, then tighten the gland nuts to prevent the wires from being pulled out.

We have designed a panel label that can be printed and affixed to the enclosure, as shown in Fig.4. A PDF file of this label can be downloaded from the November 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**

Parts List – DC Transient Filter (12V, 5A version)

1 double-sided, plated-through PCB coded 08108221, 77 × 46mm, available from the PE PCB Service
1 panel label, 80 × 47mm (**optional**)
1 UB5 Jiffy box with flanged lid **[Altronics HF0155, Jaycar HB6016]**
2 15A 2-way PCB-mount screw terminals (CON1, CON2) **[Altronics P2101]**
2 47µH 5A chokes (L1, L2) **[Altronics L6617, Jaycar LF1274]**
1 30A blade fuse holder **[Altronics S6040]**
1 5A blade fuse (F1)
2 cable glands to suit 4-8mm cable diameter
4 M3 × 10mm countersunk head (CSK) screws
4 M4 hex nuts
4 TO-220 insulating bushes
2 100mm cable ties (5A version only)
1 transient voltage suppressor rated at 1500W with a V_{BR} of 14.4-15V (TVS1) **[Jaycar ZR1170]**
1 3mm LED, any colour (LED1)
2 100nF 63V MKT capacitors
2 1µF 50V multi-layer ceramic capacitors
2 100µF 25V low-ESR electrolytic capacitors
1 4.7kΩ ½W resistor

10A version changes

1 UB3 Jiffy box **[Altronics HF0203, Jaycar HB6014]** (instead of UB5 Jiffy box)
2 powdered iron toroidal cores (L1, L2) **[Jaycar LO1244]** (instead of 47µF 5A chokes)
1 2m length of 1.25mm enamelled copper wire (for winding L1 and L2)
1 10A blade fuse (F1) (instead of 5A fuse)

Winding L1 and L2 for 10A use

The ratings of pre-wound inductors L1 and L2 limit the standard version of the Filter to 5A. The circuit can supply up to 10A by using hand-wound inductors instead.

In this case, L1 and L2 are made by winding 24 turns of 1.25mm diameter enamelled copper wire on the specified toroidal core. The ends of the wire will need to be stripped of insulation using a sharp craft knife before soldering. Keep the ends long enough so the inductors can mount raised off the PCB, as they will not fit in the space allocated for the 5A inductors.

Ideally, these inductors should be secured high enough to clear the other PCB-mounted components, but low enough to allow the assembled PCB to fit inside the enclosure. A horizontal mounting will give the best clearance; the inductor leads may need extending if they aren't left sufficiently long. You can use neutral-cure silicone sealant to secure the inductors to the PCB and adjacent components.

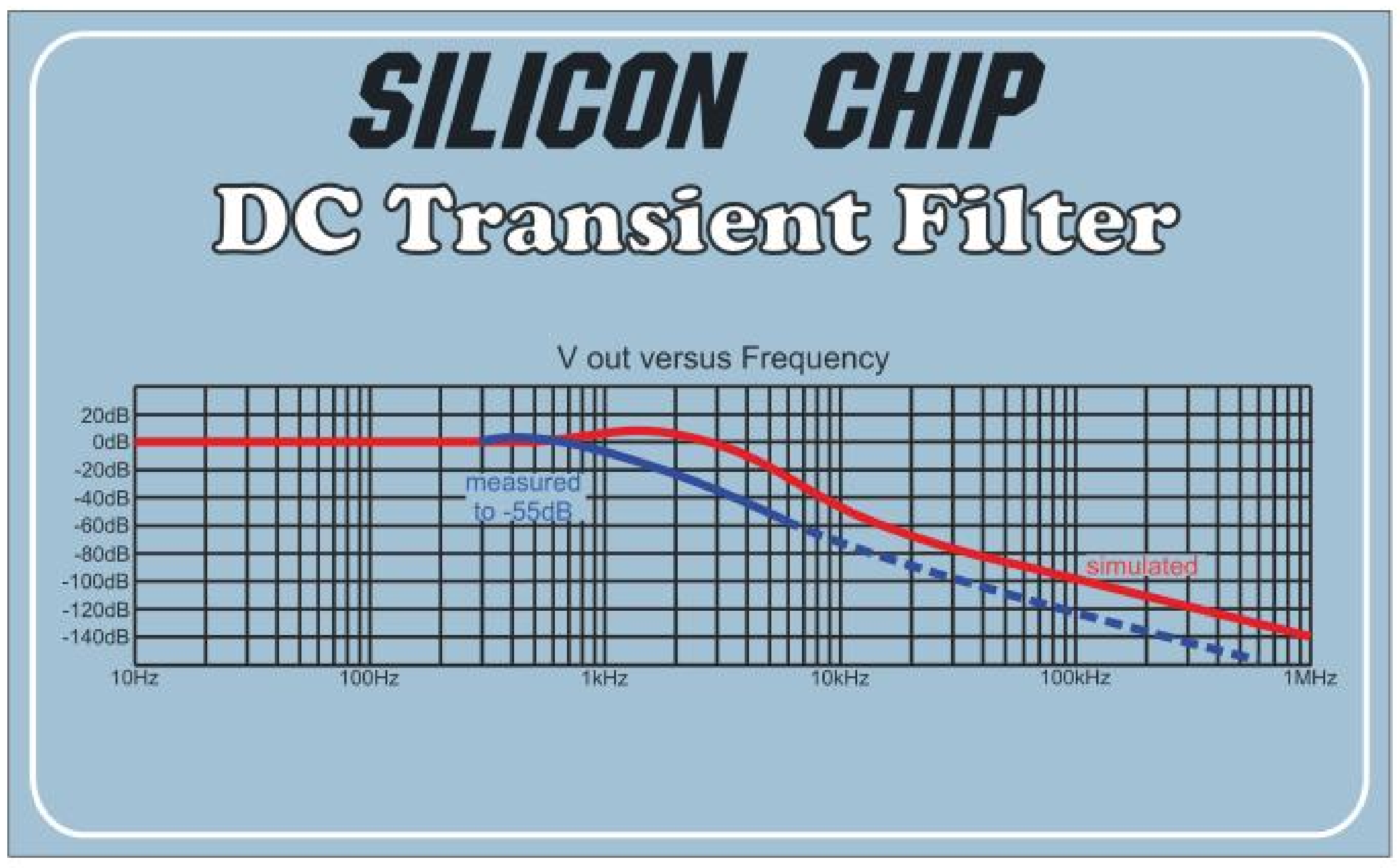
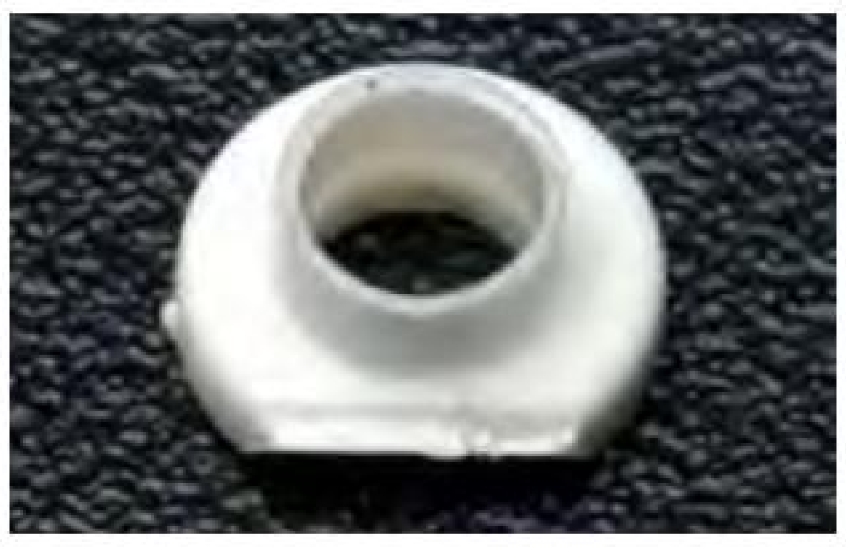


Fig.4: you can attach this panel label to the box lid, so its contents aren't a mystery.



The insulating bushes for the PCB should be trimmed to fit the lid.

This filter is suitable for use with last month's Multi-Stage Buck/Boost Charger (October 2023) for battery charging from a vehicle power supply.

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IFR 2025	Signal Generator 9kHz – 2.51GHz Opt 04/11	£900
IFR 2948B	Communication Service Monitor Opts 03/25 Avionics	POA
IFR 6843	Microwave Systems Analyser 10MHz – 20GHz	POA
R&S APN62	Syn Function Generator 1Hz – 260kHz	£295
Agilent 8712ET	RF Network Analyser 300kHz – 1300MHz	POA
HP8903A/B	Audio Analyser	£750 – £950
HP8757D	Scaler Network Analyser	POA
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
HP6032A	PSU 0-60V 0-50A 1000W	£750
HP6622A	PSU 0-20V 4A Twice or 0-50V 2A Twice	£350
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HP6632B	PSU 0-20V 0-5A	£195
HP6644A	PSU 0-60V 3.5A	£400
HP6654A	PSU 0-60V 0-9A	£500
HP8341A	Synthesised Sweep Generator 10MHz – 20GHz	£2,000
HP83630A	Synthesised Sweeper 10MHz – 26.5 GHz	POA
HP83624A	Synthesised Sweeper 2 – 20GHz	POA
HP8484A	Power Sensor 0.01-18GHz 3nW-10µW	£75
HP8560E	Spectrum Analyser Synthesised 30Hz – 2.9GHz	£1,750
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Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325
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Marconi 2030	Synthesised Signal Generator 10kHz – 1.35GHz	£750
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Marconi 2305	Modulation Meter	£250
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Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
Marconi 2955B	Radio Communications Test Set	£800
Marconi 6200	Microwave Test Set	£1,500
Marconi 6200A	Microwave Test Set 10MHz – 20GHz	£1,950
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Marconi 6960B	Power Meter with 6910 sensor	£295
Tektronix TDS3052B	Oscilloscope 500MHz 2.5GS/s	£1,250
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Farnell AP60/50	PSU 0-60V 0-50A 1kW Switch Mode	£300
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Racal 1991	Counter/Timer 160MHz 9 Digit	£150
Racal 2101	Counter 20GHz LED	£295
Racal 9300	True RMS Millivoltmeter 5Hz – 20MHz etc	£45
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Solartron 7150/PLUS	6½ Digit DMM True RMS IEEE	£65/£75
Solatron 1253	Gain Phase Analyser 1mHz – 20kHz	£600
Solartron SI 1255	HF Frequency Response Analyser	POA
Tasakago TM035-2	PSU 0-35V 0-2A 2 Meters	£30
Thurlby PL320QMD	PSU 0-30V 0-2A Twice	£160 – £200
Thurlby TG210	Function Generator 0.002-2MHz TTL etc Kenwood Badged	£65

HP/Agilent HP 34401A Digital
Multimeter 6½ Digit £325 – £375

HP33120A	Function Generator 100 microHz – 15MHz	£350
HP53131A	Universal Counter 3GHz Boxed unused	£600
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Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

Marconi 2955B Radio
Communications Test Set – £800

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Using Electronic Modules with Jim Rowe

PM (particulate matter) ‘Dust’ Sensors

In this last article on low-cost air quality sensors, we look more closely at particulate matter (PM) sensors, also called ‘dust’ or ‘smoke’ sensors.

As mentioned in the first of these articles, PM sensors fall into three groups based on the size of the particles they are designed to detect: less than 10μm (PM10), less than 2.5μm (PM2.5) and less than 1μm (PM1.0). Currently, PM2.5 types are the most common in the low-cost section of the market, so we’ll concentrate on modules that support it.

The basic principle of the most common type of PM sensor is shown in Fig.1. This was described in the first article but we’ll briefly go over it again. A small fan pulls air from the surrounding environment into a channel which passes through a sensing chamber. A laser sends a focused beam of light through the chamber, and any particles in the air scatter the light towards the sides of the chamber.

One or more photodiodes detect this scattered light on the sides of the chamber. Any light not scattered by particles passes through the chamber to be absorbed by the ‘beam dump’.

By controlling the fan speed and thus moving the air through the sensing chamber at a known rate of volume and measuring the photodiodes’ output, the concentration of particles in the air can be calculated.

The result is in terms of μg/m^3 (micrograms per cubic metre), because the traditional and most accurate way of measuring PM is the ‘gravimetric’ method. This involves using a pre-weighed clean filter to collect particles from the air over a 24-hour sampling period, then weighing the filter again to determine the total mass of the accumulated particles in micrograms.

The concentration is then obtained by dividing this figure by the total volume of air that passed through the filter during the 24-hour sampling period.

Available PM modules

There are several low-cost PM sensors currently available, including the Grove-Laser Sensor module, based on the Seeed Studio HM3301 sensor from Shenzhen, China, and the SN-GCJA5 sensor made by Panasonic Photo and Lighting Co in Osaka, Japan.

The first is a fan-type sensor, as shown in Fig.1. But other types of PM sensor modules do not have an internal fan, including the Panasonic SN-GCJA5 and the XC3780 from Jaycar, based on the Sharp GP2Y1010AU sensor. We will look at all three of these sensor modules in this article.

The Grove-Laser module

The Seeed Studio HM3301 sensor comes inside a compact plastic and metal case measuring 38 × 40 × 15mm. In addition to the fan, laser and photodiodes, it has built-in electronics that provide fan control,

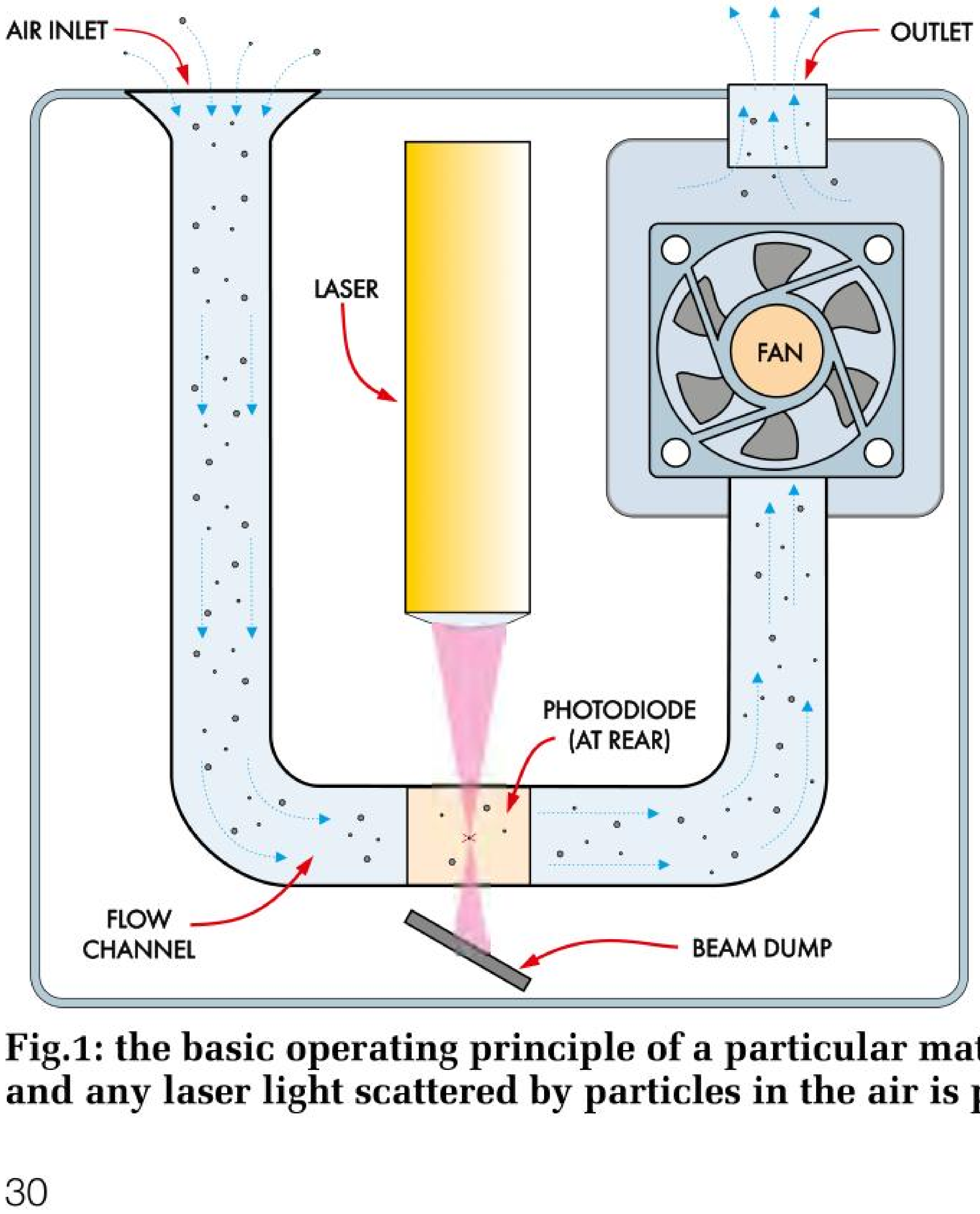
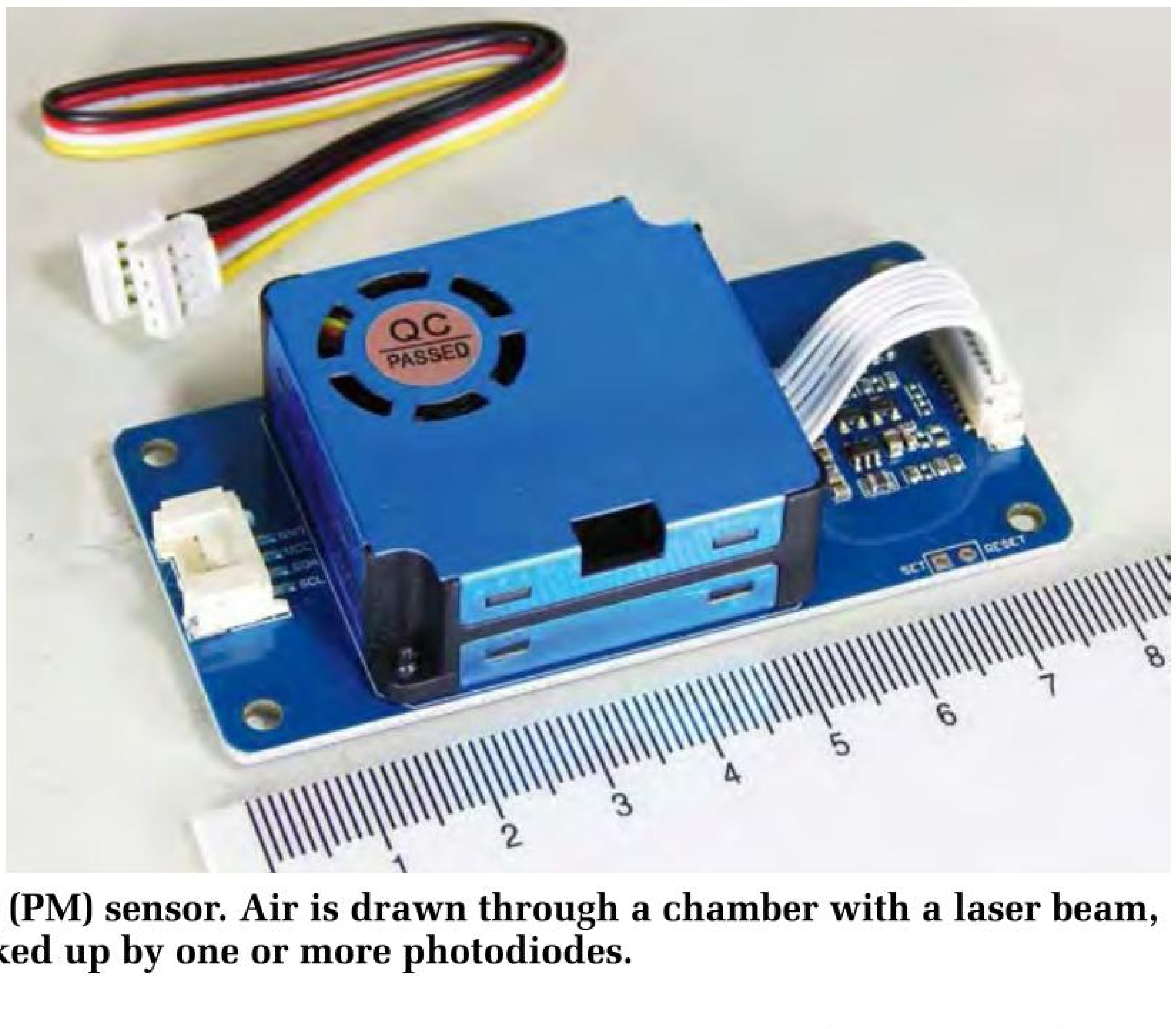


Fig.1: the basic operating principle of a particular matter (PM) sensor. Air is drawn through a chamber with a laser beam, and any laser light scattered by particles in the air is picked up by one or more photodiodes.

The Grove-Laser air sensor module is based on the Seeed HM3301 particulate matter sensor. The sensor itself measures 38 x 40 x 15mm and the module comes with a suitable cable.



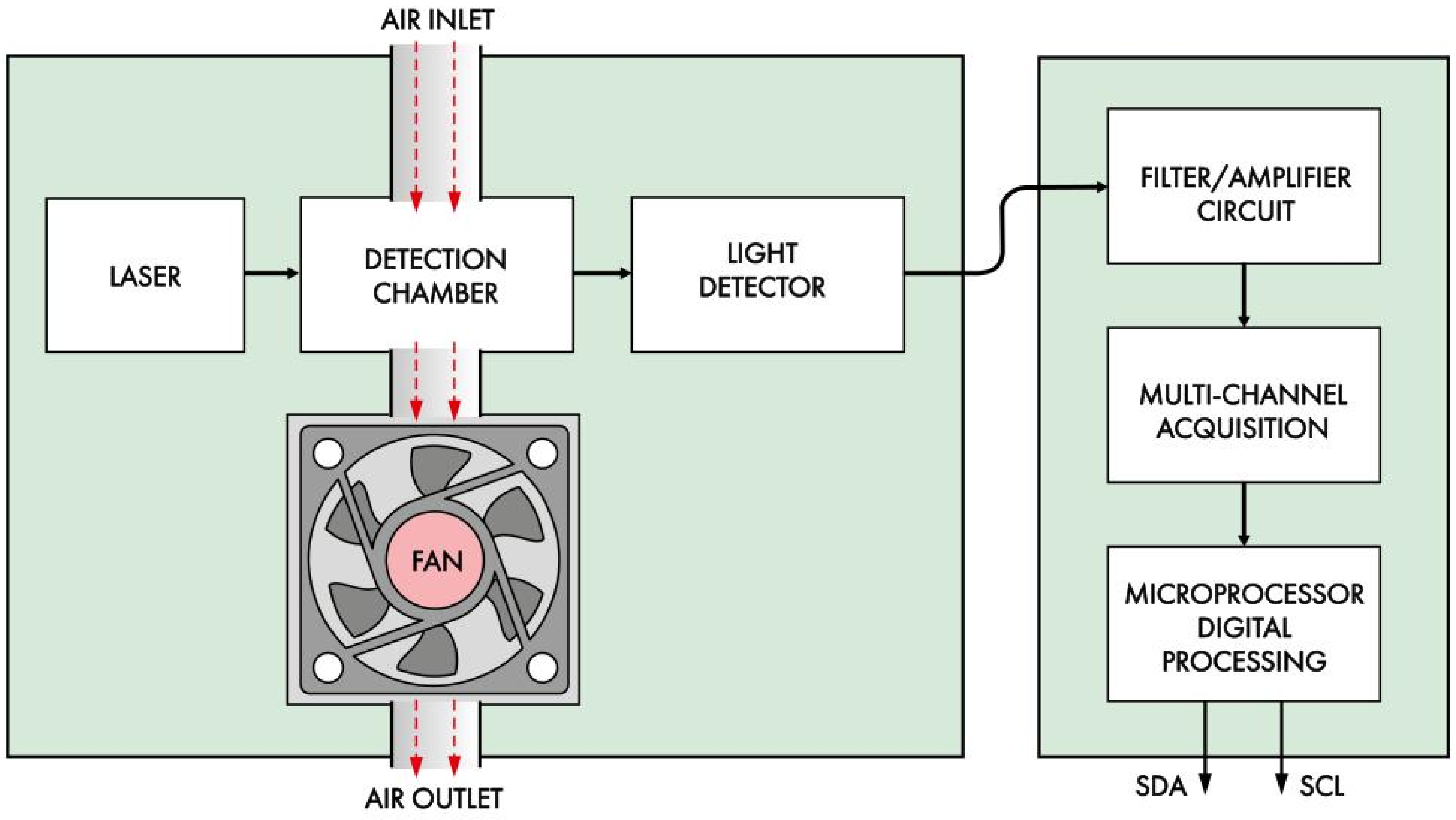
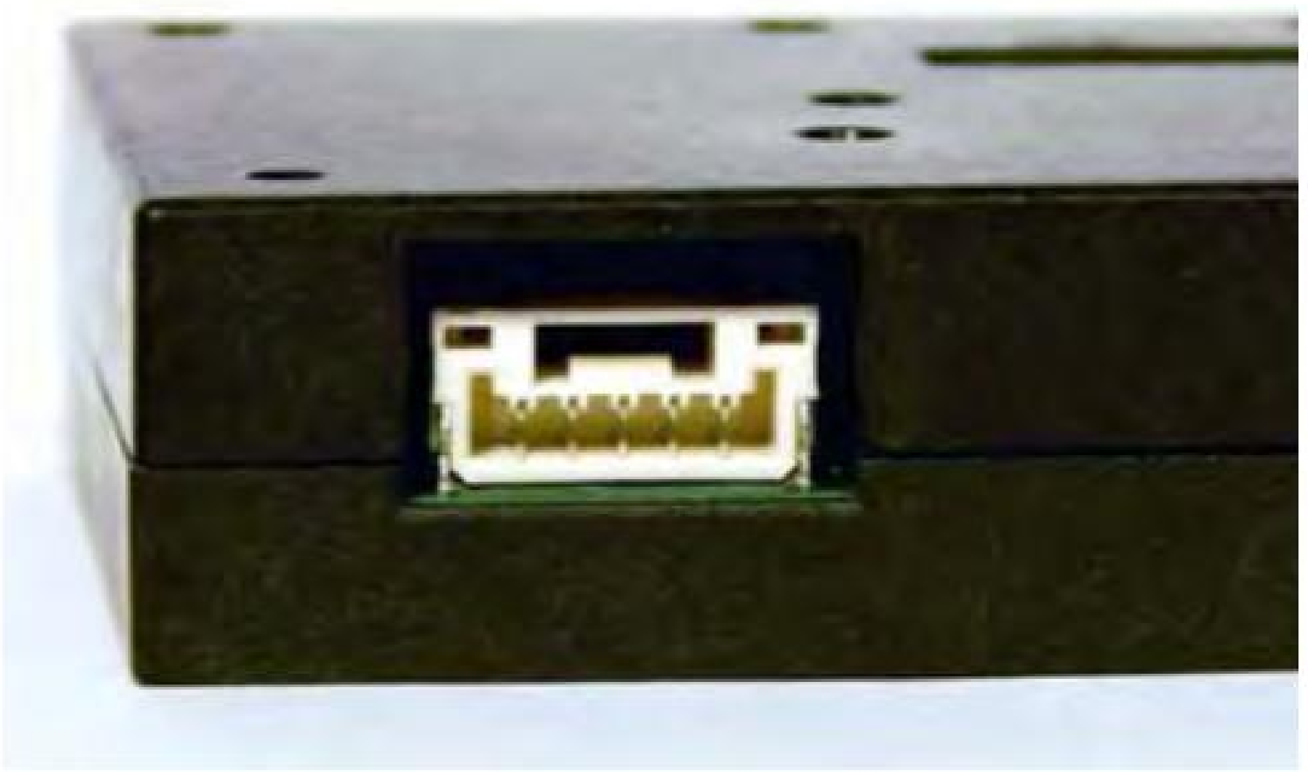

AIR INLET
LASER
DETECTION CHAMBER
LIGHT DETECTOR
FAN
AIR OUTLET
FILTER/AMPLIFIER CIRCUIT
MULTI-CHANNEL ACQUISITION
MICROPROCESSOR DIGITAL PROCESSING
SDA
SCL

Fig.2: the components of the HM3301 sensor. The part at left is basically identical to what's shown in Fig.1, while the section at right shows the electronics that pick up the scattered light level and turn it into a digital measurement.



External connections to the SN-GCJA5 sensor are via a tiny 5-way JST connector with 1.25mm pin spacing. No matching cable is supplied, which is a bit of a problem as they are hard to find!

photodiode signal amplification, filtering, multi-channel data acquisition and an MCU (microcontroller unit) for data processing. The output is via a two-wire I^{2}C serial interface.

In the Grove-Laser module, the HM3301 sensor is mounted on a PCB measuring 80 × 40mm, with a four-pin connector at one end for connections to a 3.3-5V power supply and the I^{2}C lines for connection to a PC or an external MCU. The effective PM2.5 measuring range of the module is 1-500µg/m^3, although it can measure up to a maximum level of 1000µg/m^3.

This module is available from multiple online vendors from around £30-£40.

Fig.2 shows a functional block diagram of what's inside the HM3301 sensor. The actual PM measuring section with the fan, laser, detection chamber, and photodiode detector is on the left. On the right is the electronics section with its filter/amplifier, multi-channel acquisition and internal MCU for digital signal processing and the I^{2}C data communication interface.

Since the HM3301 sensor operates from a 3.3-5V DC supply and has a standard I^{2}C interface, connecting the module to an Arduino module or similar is relatively straightforward. A sample connection scheme is shown in Fig.3.

Note that although the HM3301 sensor itself has no internal pull-up resistors on the SDA or SCL lines, the Grove-Laser module provides pull-up resistors plus logic-level converters on its PCB. That's why the connections shown in Fig.3 are so straightforward.

Of course, wiring the module up is only part of the story. You also need software that can communicate with it and display the results. So if you want to use it with an Arduino, you'll need both a matching library and a sketch designed to communicate with the HM3301 sensor using it.

When I went to the 'Reference' section of the Arduino website and scrolled down through the Libraries/Sensors list, I found a library that had clearly been produced to do the job: 'grove-laser-pm2.5-sensor-hm3301'. And when I clicked on 'Read the documentation' on its page, it took me to GitHub, where I found both the documentation and a link to download the library (v1.0.2).

After downloading and installing the library, I found that it came with an example program called **basic_demo.ino**. After verifying and uploading that program 'sketch' to an Arduino Uno connected to the Grove-Laser module as per Fig.3, the Arduino IDE's Serial Monitor (set to a baud rate of 115,200) sprang into life.

I immediately saw the text shown in Fig.4, with two sets of PM1.0, PM2.5 and PM10 measurements appearing every five seconds.

The example output shown in Fig.4 is higher than normal (it should

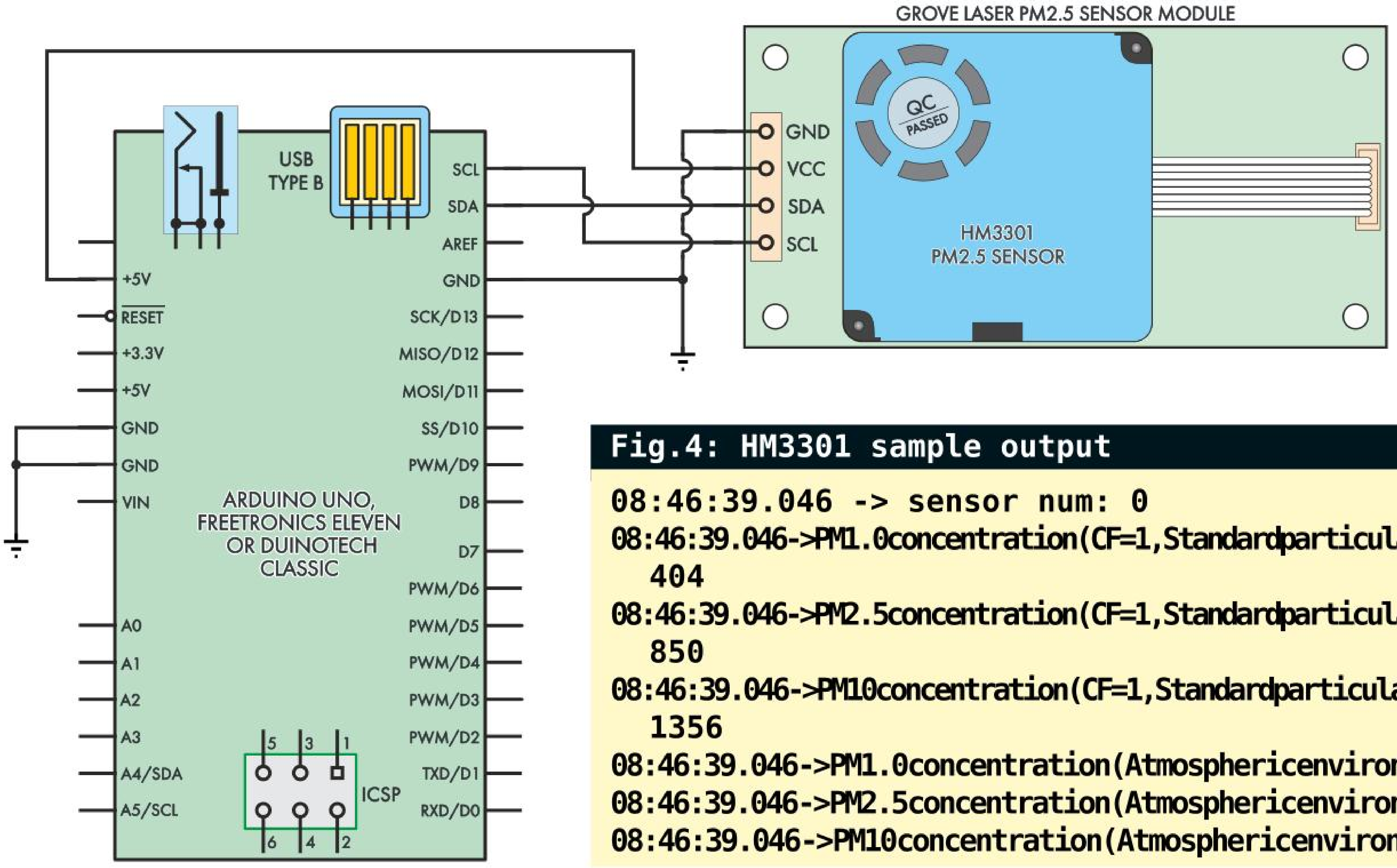
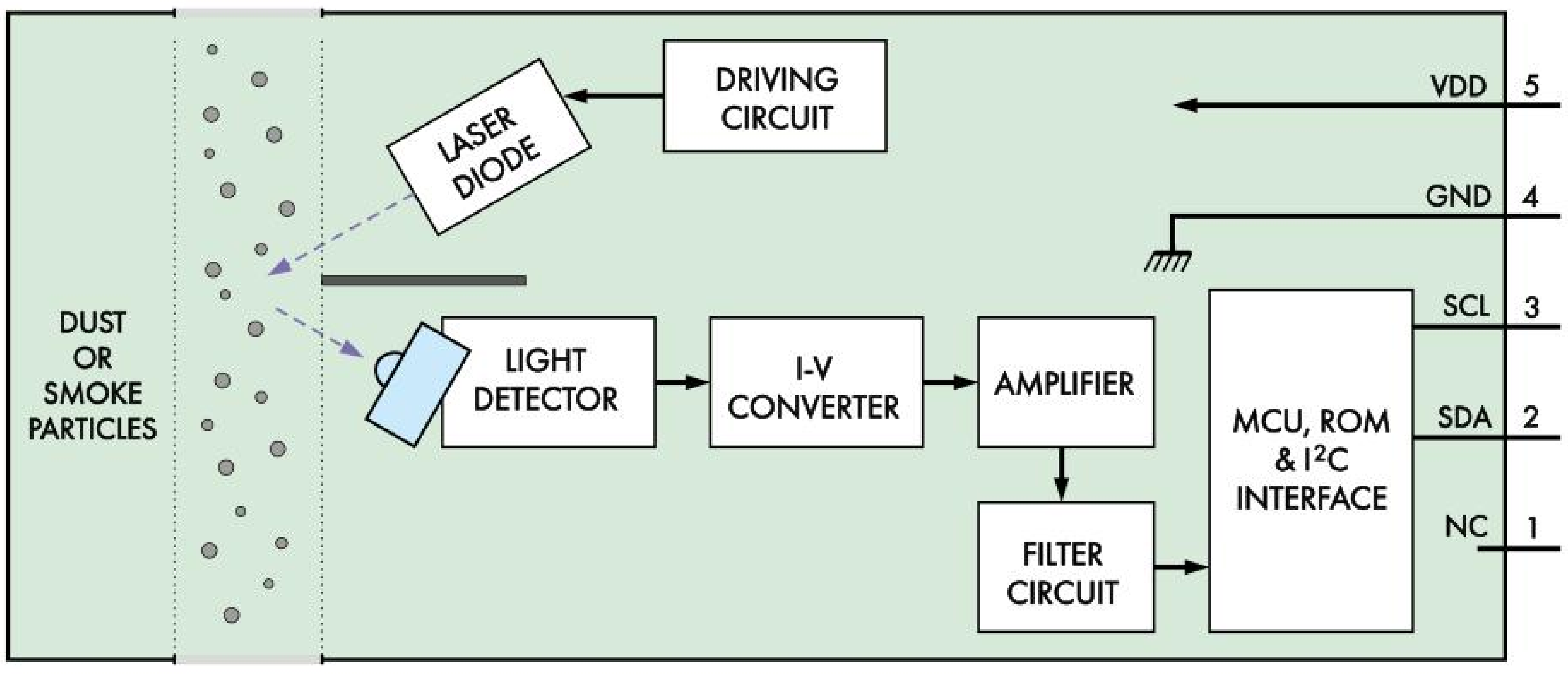

GROVE LASER PM2.5 SENSOR MODULE
GND
VCC
SDA
SCL
QC PASSED
HM3301 PM2.5 SENSOR
USB TYPE B
SCL
SDA
AREF
GND
SCK/D13
MISO/D12
MOSI/D11
SS/D10
PWM/D9
D8
D7
PWM/D6
PWM/D5
PWM/D4
PWM/D3
PWM/D2
TXD/D1
RXD/D0
+5V
RESET
+3.3V
+5V
GND
GND
VIN
ARDUINO UNO, FREETRONICS ELEVEN OR DUINOTECH CLASSIC
A0
A1
A2
A3
A4/SDA
A5/SCL
5
3
1
6
4
2
ICSP

Fig.3: connecting the Grove HM3301 module to an Arduino is simple. All it needs is a ground connection, a 5V DC supply and the SDA and SCL pins connected to an I^{2}C bus.

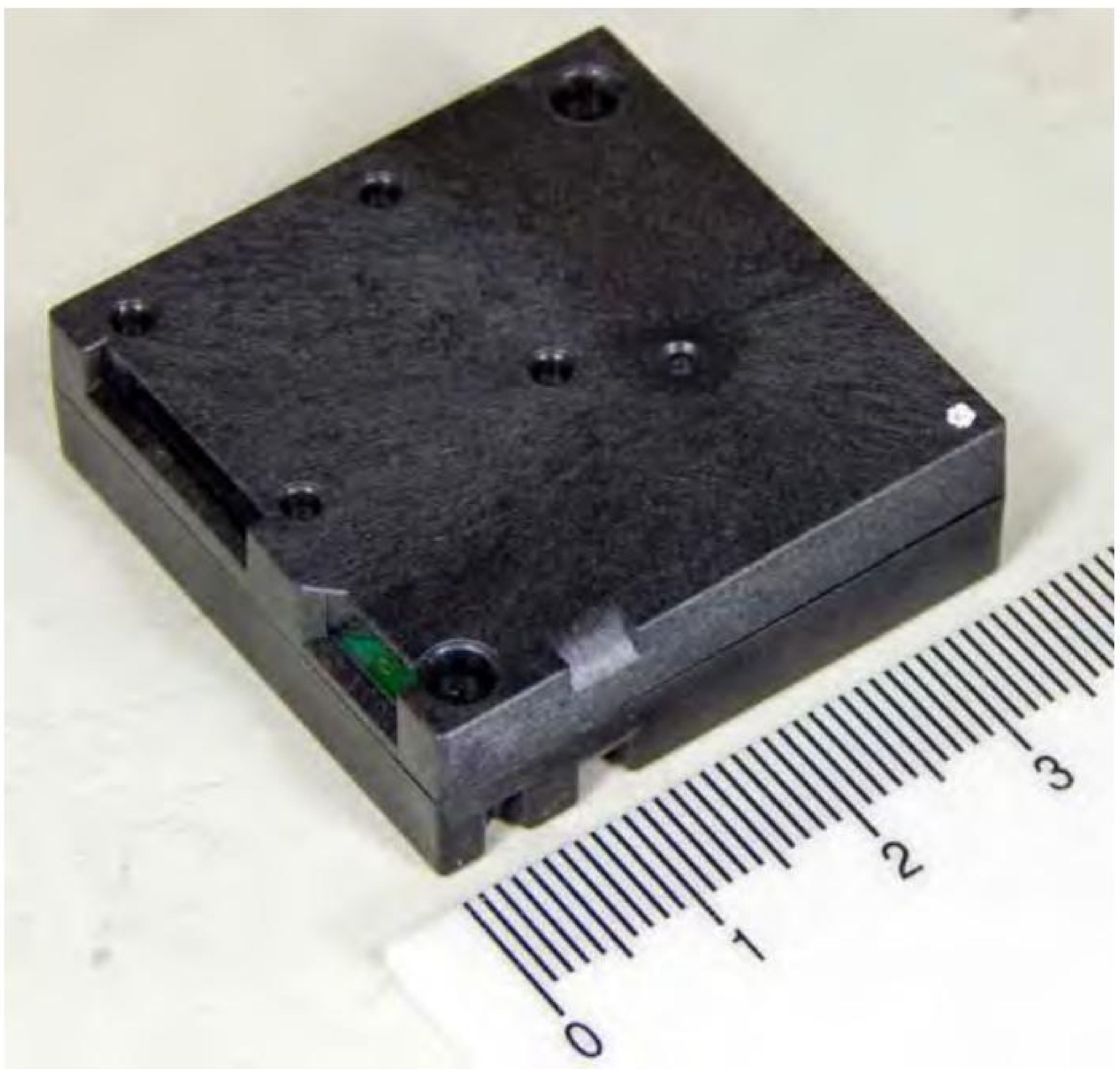
Fig.4: HM3301 sample output

```
08:46:39.046 -> sensor num: 0
08:46:39.046->PM1.0concentration(CF=1,Standardparticulatematter,unit:ug/m3):
  404
08:46:39.046->PM2.5concentration(CF=1,Standardparticulatematter,unit:ug/m3):
  850
08:46:39.046->PM10concentration(CF=1,Standardparticulatematter,unit:ug/m3):
  1356
08:46:39.046->PM1.0concentration(Atmosphericenvironment,unit:ug/m3):266
08:46:39.046->PM2.5concentration(Atmosphericenvironment,unit:ug/m3):524
08:46:39.046->PM10concentration(Atmosphericenvironment,unit:ug/m3):776
```


DRIVING CIRCUIT
LASER DIODE
VDD 5
GND 4
SCL 3
SDA 2
NC 1
DUST OR SMOKE PARTICLES
LIGHT DETECTOR
I-V CONVERTER
AMPLIFIER
MCU, ROM & I²C INTERFACE
FILTER CIRCUIT

▲
Fig.5: the Panasonic SN-GCJA5-PM sensor does not use a fan. It instead relies on passive diffusion of air through its sensing channel. Otherwise, its structure is similar to the HM3301 shown in Fig.2.

The Panasonic SN-GCJA5 particulate matter sensor is in a small moulded plastic case measuring 37 x 37 x 12mm. In addition to the laser and photodetector, it contains all of the electronics and provides both I^{2}C and UART digital outputs. ▶



be just above zero). That's because I struck a match and blew it out just before that, blowing the smoke towards the HM3301 sensor. The readings jumped up quite quickly but went back to normal after about 10 seconds.

So while it's not particularly low in cost, the Grove-Laser PM module is easy to use and seems quite sensitive.

Panasonic SN-GCJA5 sensor

The Panasonic SN-GCJA5 sensor is again mounted inside a compact moulded plastic box that measures 37 × 37 × 12mm and weighs 13g. As with the HM3301 sensor, it includes electronics to control the laser and amplify and filter the signals from the photodiodes, plus an MCU for data processing.

The output is via either an I^{2}C or a UART TX terminal. The effective measuring range of this module is 0-2000µg/m^3.

The Panasonic SN-GCJA5 sensor dips in and out of stock from major UK online vendors and is usually quoted at around £20.

Fig.5 shows what is inside the SN-GCJA5 sensor. As you can see, it's similar to the HM3301 sensor innards shown in Fig.2, apart from not having any internal fan to move the air through the detection chamber.

Since it has an I^{2}C interface, it connects to an MCU like the Arduino in much the same way as the Grove-Laser module, as shown in Fig.6. But there's one small but significant problem: connections to the SN-GCJA5 sensor are all made via a tiny 5-pin 'pico' connector at one end, but a connection cable with a matching plug is not supplied with it.

So if you want to use – or even try out – the sensor, you first need to obtain a matching cable.

Panasonic's data sheet for the SN-GCJA5 sensor states that its connector is made by JST (Japan Solderless Terminals) Manufacturing Company, and has the type number SM05B-GHS-TB(LF)(SN). I had a lot of trouble finding any compatible cables – most cables I found with similar connectors turned out to have pins either 1.0mm or 1.5mm apart, not the 1.25mm of the JST SM05B-GHS-TB(LF)(SN).

Just as I was on the brink of concluding that I would not be able to try out the SN-GCJA5 sensor, a colleague emailed me to say that he believed he had found a supplier of compatible cables on AliExpress (**www.aliexpress.com/item/33005797784.html**). I quickly checked them out and then ordered a pack of 10 (the smallest quantity). These cost a grand total of £7.50 including postage, packing and VAT, and they took quite a few weeks to arrive.

But they did finally arrive, and I used one (or half of one, to be precise)

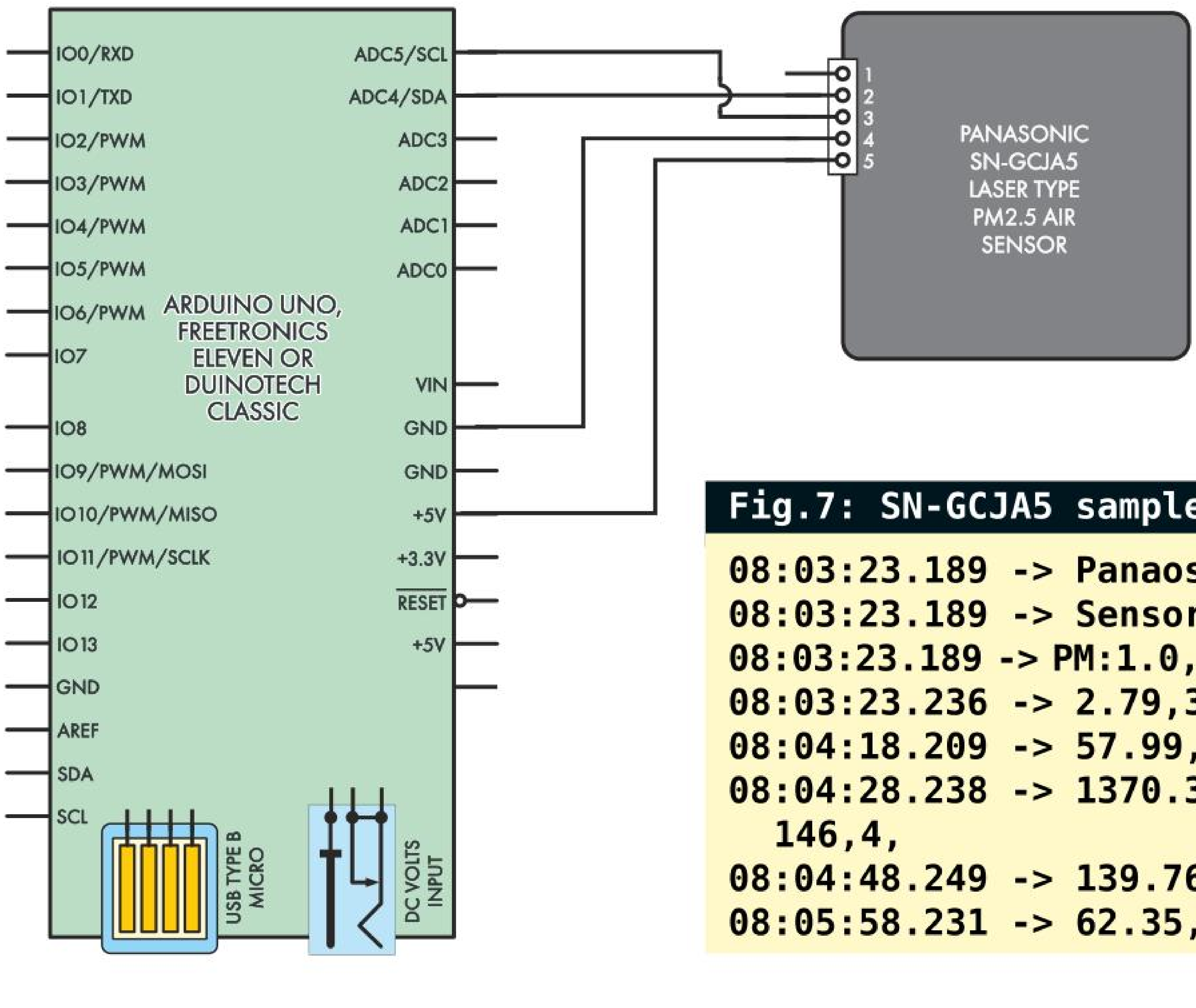
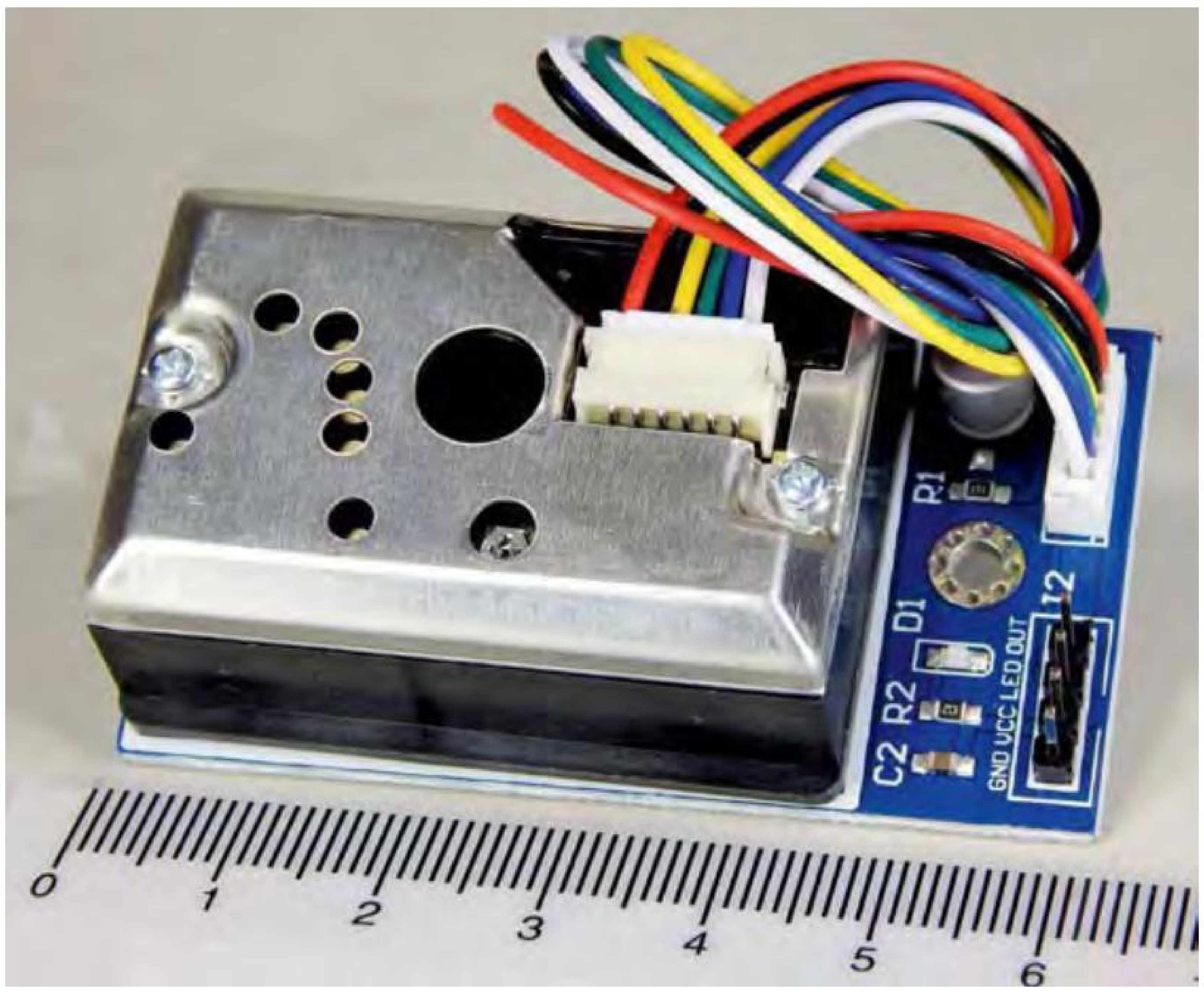

IO0/RXD
IO1/TXD
IO2/PWM
IO3/PWM
IO4/PWM
IO5/PWM
IO6/PWM
IO7
IO8
IO9/PWM/MOSI
IO10/PWM/MISO
IO11/PWM/SCLK
IO12
IO13
GND
AREF
SDA
SCL
ADC5/SCL
ADC4/SDA
ADC3
ADC2
ADC1
ADC0
VIN
GND
GND
+5V
+3.3V
RESET
+5V
ARDUINO UNO, FREETRONICS ELEVEN OR DUINOTECH CLASSIC
USB TYPE B MICRO
DC VOLTS INPUT
1
2
3
4
5
PANASONIC SN-GCJA5 LASER TYPE PM2.5 AIR SENSOR

Fig.6: connecting the Panasonic SN-GCJA5 module to an Arduino is again simple. All you need to do is connect a 5V DC supply, a ground connection and the I^{2}C bus via the SCL and SDA pins. Pin 1 isn't used for anything, nor does it have any function.

Fig.7: SN-GCJA5 sample output

```
08:03:23.189 -> Panaosnic SN-GCJA5 Example
08:03:23.189 -> Sensor started
08:03:23.189 -> PM:1.0, 2.5, 10, Counts: 0.5, 1, 2.5, 5, 7.5, 10,
08:03:23.236 -> 2.79,3.12,3.50,5,32,4,0,0,0,
08:04:18.209 -> 57.99,135.45,448.29,39,598,801,13,71,2,
08:04:28.238 -> 1370.39,1730.99,2392,60,440,3824,3759,37,
  146,4,
08:04:48.249 -> 139.76,154.51,173.83,513,1210,153,1,2,0,
08:05:58.231 -> 62.35,73.86,83.09,200,591,120,1,0,0,
```



VCC
OUT
S-GND
LED
GND-LED
V-LED
OUT
LED
VCC
GND
duinotech

The Jaycar XC3780 module is based on the Sharp GP2Y1010AU dust sensor. Being fanless, it relies on air diffusing through 7.5mm diameter holes in the top and bottom of the sensor's case. It has a varying DC voltage output rather than digital outputs, so conversion into a dust density figure is done by software running on the controlling MCU.

to hook up the sensor to an Arduino and try it out.

I needed to find a suitable Arduino library to communicate with the SN-GCJA5. Luckily, I found one in the Arduino website Reference section at: **https://bit.ly/pe-nov23-GCJA5**

When I downloaded this library and installed it, I found that it again included some example sketches. The first of these was called **Example1_BasicReadings.ino**. When I verified and uploaded this sketch to the Arduino Uno connected to the SN-GCJA5 sensor, as shown in Fig.6, it finally sprang into life. Once again, I had to set the Arduino IDE Serial Monitor to 115,200 baud.

You can see the output of the sketch in Fig.7. It gives three PM readings (1.0, 2.5 and 10) at the start of each sample line, followed by six Count figures (labelled 0.5, 1, 2.5, 5, 7.5 and 10). The first three figures are the 'mass densities' for the three main particle categories, while the later figures are 'particle counts' for all six particle size categories.

Looking at Fig.7, the first values outputted are pretty low, they then shoot up to much higher levels after I lit a match about 150mm from the sensor and then blew it out, blowing the smoke towards the sensor.

So the Panasonic SN-GCJA5 sensor does work, and even works quite well, once you manage to find a suitable cable to connect to it. It would be a lot easier if they supplied a matching cable!

The Jaycar XC3780 sensor

As mentioned earlier, Jaycar's XC3780 dust sensor module is based on the Sharp GP2Y1010AU fanless sensor. The sensor itself is pretty compact, measuring 46 × 30 × 17.5mm, and the XC3780 module is only a little larger, at 62 × 35 × 19mm. 7.5mm diameter holes in the top and bottom of the sensor (and the PCB) allow air containing any particulate matter, dust or smoke to diffuse through the sensor.

At the time of writing, the XC3780 module is available from Jaycar stores for £12.50.

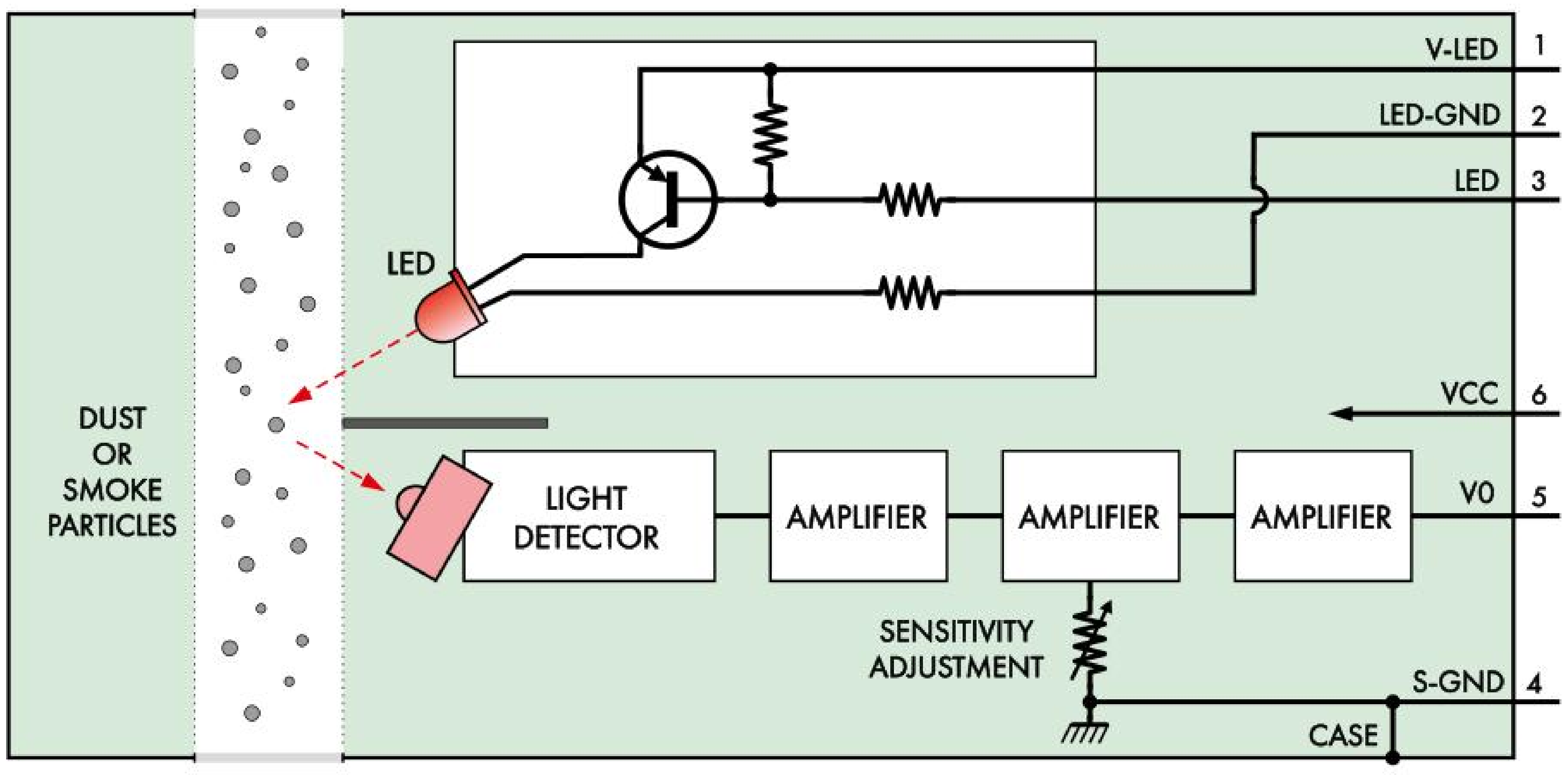


Fig.8: the main difference between this GP2Y1010AU 'dust' sensor and the Panasonic sensor shown in Fig.5 is that this one lacks any digital control electronics; it only includes analogue signal processing. Therefore, the driving microcontroller module must power the LED via pins 1-3, measure the voltage at output pin 5 and convert that into a particle level.

Because the sensor's mini six-pin SIL connector is on the top of the case, the XC3780 module comes with a short six-wire cable connecting it to a matching mini SIL connector on the end of the module's PCB. There are some passive components at the same end of the board plus a four-pin SIL header with standard 0.1in/2.54mm spacing, to simplify connection to an external MCU.

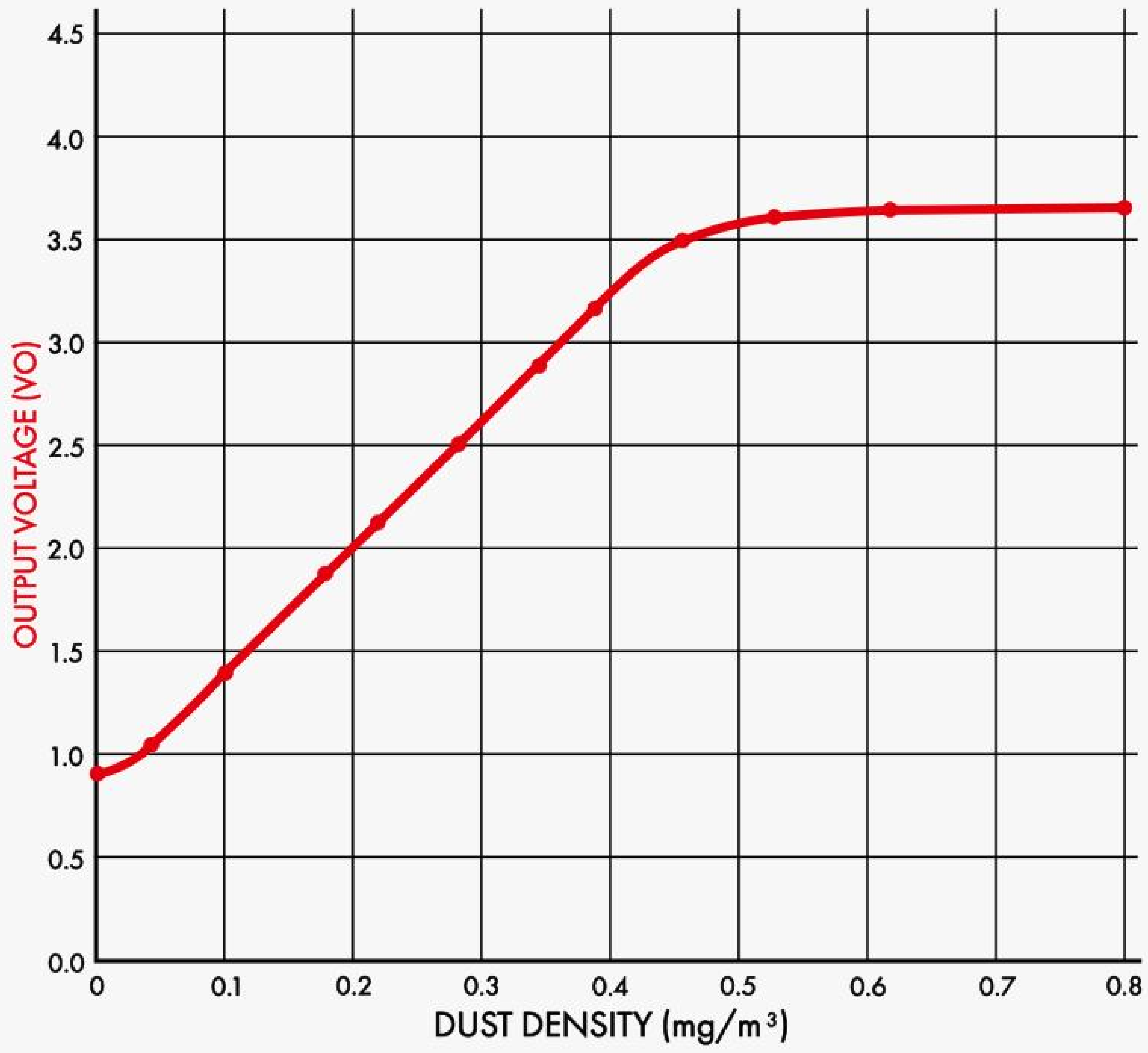
Fig.8 shows the components inside the GP2Y1010AU sensor itself, and as you can see, it's similar to Fig.5 apart from not having a microcontroller to digitise and process the output signal. In this case, the analogue output signal 'VO' is simply made available at pin 5.

Note that the centre amplifier section has a small adjustable resistor or trimpot to adjust the sensor's effective sensitivity. But the Sharp data sheet for the GP2Y1010AU sensor warns that this trimpot is set to make the sensor conform to its specification before shipment. As a result, they advise against further adjustment of the trimpot.

This specification is summarised in Fig.9, which shows how the output voltage (VO) varies with dust density. VO is close to 0.9V with zero dust in the air, rising relatively linearly to about 3.25V at a dust density of 0.4mg/m^3 before flattening off at about 3.55V for a dust density of 0.53mg/m^3. It then rises very slowly to about 3.6V for a dust density of 0.8mg/m^3. Note that 1mg = 1000µg.

The complete circuit of the XC3780 module is shown in Fig.10, and there are only a few passive components on the PCB apart from the GP2Y1010AU sensor itself. The 150Ω resistor and 220µF capacitor provide decoupling and smoothing for the supply to the sensor's internal LED, while the 1kΩ

Fig.9: this curve shows the transfer function between the output voltage of the GP2Y1010AU sensor and the corresponding dust density in mg/m³. A table (or similar) representing the points in this plot needs to be loaded into the microcontroller to perform this conversion.



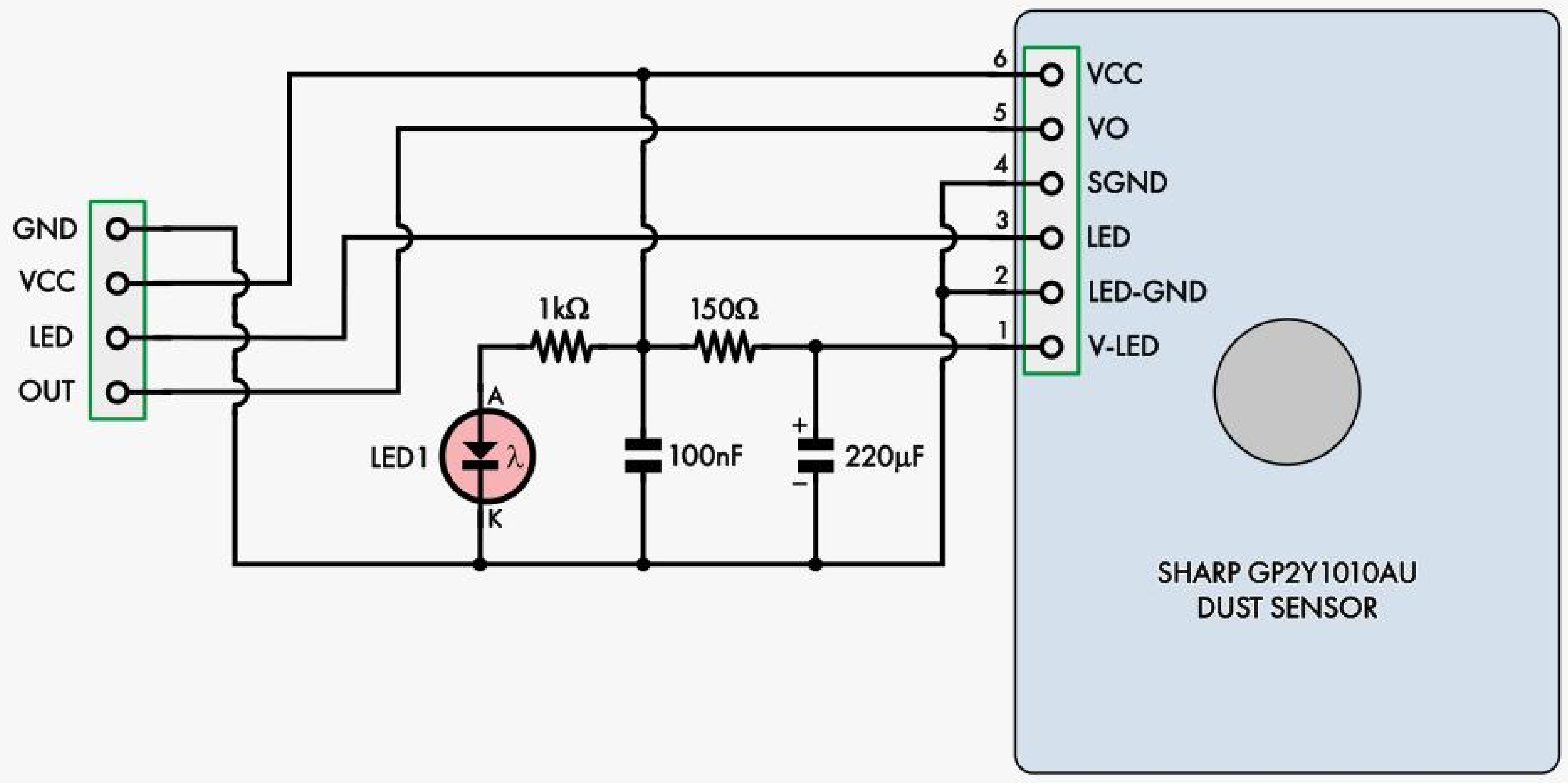

GND
VCC
LED
OUT
1kΩ
150Ω
A
K
LED1
λ
100nF
+
–
220µF
6
5
4
3
2
1
VCC
VO
SGND
LED
LED-GND
V-LED
SHARP GP2Y1010AU
DUST SENSOR

Fig.10: there aren't many components on the Jaycar XC3780 module besides the Sharp sensor. All they do is filter the power supply to the module, provide a power-on indication via LED1 and route the necessary signals to a standard four-pin header for connection to an MCU.

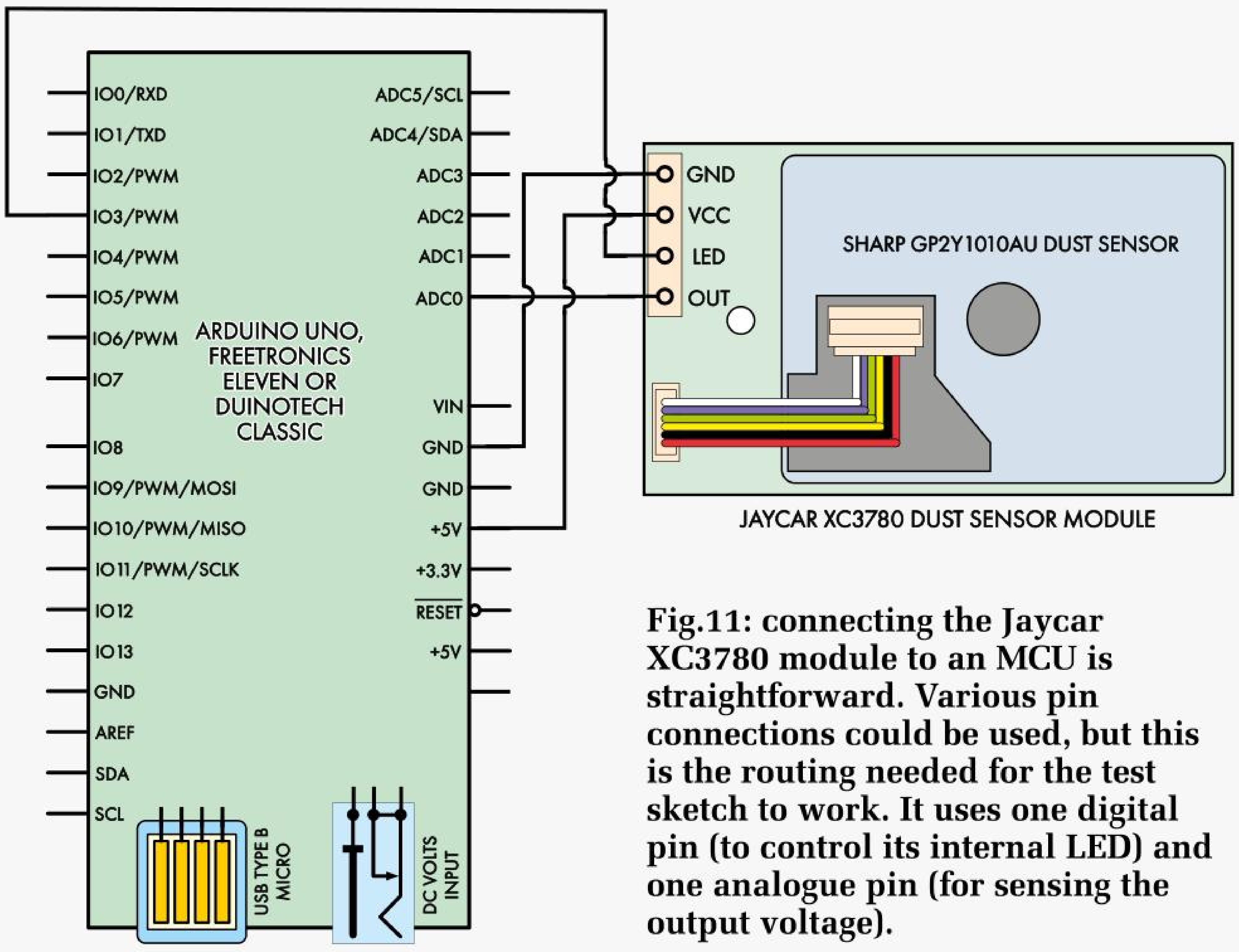

IO0/RXD
IO1/TXD
IO2/PWM
IO3/PWM
IO4/PWM
IO5/PWM
IO6/PWM
IO7
IO8
IO9/PWM/MOSI
IO10/PWM/MISO
IO11/PWM/SCLK
IO12
IO13
GND
AREF
SDA
SCL
ADC5/SCL
ADC4/SDA
ADC3
ADC2
ADC1
ADC0
VIN
GND
GND
+5V
+3.3V
RESET
+5V
ARDUINO UNO, FREETRONICS ELEVEN OR DUINOTECH CLASSIC
USB TYPE B MICRO
DC VOLTS INPUT
GND
VCC
LED
OUT
SHARP GP2Y1010AU DUST SENSOR
JAYCAR XC3780 DUST SENSOR MODULE

Fig.11: connecting the Jaycar XC3780 module to an MCU is straightforward. Various pin connections could be used, but this is the routing needed for the test sketch to work. It uses one digital pin (to control its internal LED) and one analogue pin (for sensing the output voltage).

resistor and LED1 indicate when the module is powered up.

Connecting the XC3780 module to an Arduino is quite straightforward, as shown in Fig.11. The GND and VCC pins of the module can be connected to the GND and +5V pins of the Arduino. The LED pin should be connected to the IO3 (D3) pin of the Arduino while the VO/OUT pin goes to the Arduino's ADC0 (A0) input.

These are the connections needed to ensure that the XC3780 module works correctly when a specific sketch runs on the Arduino. That sketch uses a particular library to control the LED inside the GP2Y1010AU and convert its DC output voltage into the equivalent dust density.

I found this library on the Arduino website in the reference → libraries → sensors section. Called PMsensor, it was written by JongHyun Woo, and the latest version is 1.1.0. When I downloaded this library (**PMsensor-master.zip**') and installed it in my Arduino IDE, I found that it came with an example sketch called **PMsensor_demo.ino**.

This sketch provides almost no information on the correct connections for the sensor's LED and VOUT lines, or the correct baud rate to use for the Arduino link back to the PC. However, after examining the code in the sketch, I determined that the proper connections were those shown in Fig.11, and the correct baud rate was 9600 baud. I then powered it up and got the result shown in Fig.12.

I decided to adapt JongHyun Woo's sketch into one with more helpful information in a 'header' section. I called this new sketch **SC_PMsensor_demo.ino** and it is available to download for free from the November 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**

As you can see from Fig.12, this sketch simply pulses the sensor's internal LED once per second, then reads its output voltage and converts it into an equivalent dust density reading. This is then printed in the lines reading 'Filter : XXX.XX'.

You may have noticed in Fig.12 that at the top of the listing, the readings are low. But then they started rising because I struck a match and blew it out with the smoke passing over the top of the sensor.

Precisely what these figures mean is not too clear, though. They could represent the dust density in µg/m³ (micrograms per cubic metre), or they might not.

So the XC3780 dust sensor can be connected fairly easily to an MCU like an Arduino, and it does work using

Fig.12: XC3780 sample output

```
15:15:25.825 -> Read PM2.5
15:15:25.825 -> Filter: 11.15
15:15:26.762 -> ========================
15:15:26.809 -> Read PM2.5
15:15:26.809 -> Filter: 30.79
15:15:27.793 -> ========================
15:15:27.840 -> Read PM2.5
15:15:27.840 -> Filter: 78.10
15:15:28.824 -> ========================
15:15:28.824 -> Read PM2.5
15:15:28.871 -> Filter: 120.76
15:15:29.808 -> ========================
15:15:32.854 -> Read PM2.5
15:15:32.901 -> Filter: 253.01
15:15:33.839 -> ========================
15:15:40.962 -> Read PM2.5
15:15:40.962 -> Filter: 396.47
15:15:41.946 -> ========================
```

We assume the readings are in μg/m^3 but the documentation is a bit vague

Useful links

Suppliers

- www.pakronics.com.au
- https://au.element14.com/3523840
- www.jaycar.com.au

Software libraries

- www.arduino.cc/reference/en/libraries/grove-laser-pm2.5-sensor-hm3301
- https://github.com/Seeed-Studio/Seeed_PM2_5_sensor_HM3301
- www.arduino.cc/reference/en/libraries/pmsensor/
- https://github.com/ekkai/PMsensor
- https://github.com/sparkfun/SparkFun_Particle_Sensor_SN-GCJA5_Arduino_Library

Panasonic SN-GCJA5 data sheet

- https://bit.ly/pe-nov23-PM

Sharp dust sensor application note

- https://bit.ly/pe-nov23-sharp

JongHyun Woo's library and demo sketch. But the accuracy and significance of its readings are a tad indeterminate.

The bottom line

Overall, I prefer the Grove-Laser module based on the HM3301 fan sensor. It is the most expensive of the three, but not unreasonably so, considering its ease of use and the apparent accuracy of its readings.

I would have to rate the Panasonic SN-GCJA5 sensor as the next best; although it seems to give fairly accurate readings, it lacks a fan and also has the disadvantage of not coming with a matching cable.

The Jaycar XC3780 module is only about half the cost of the other two modules/sensors and is the easiest to get.

However, the fact that it needs software running in the Arduino to convert its DC output voltage into dust density makes me a little less confident in the accuracy of its readings. Still, it would probably be fine if all you needed were relative readings – eg, to use it as a kind of smoke alarm.

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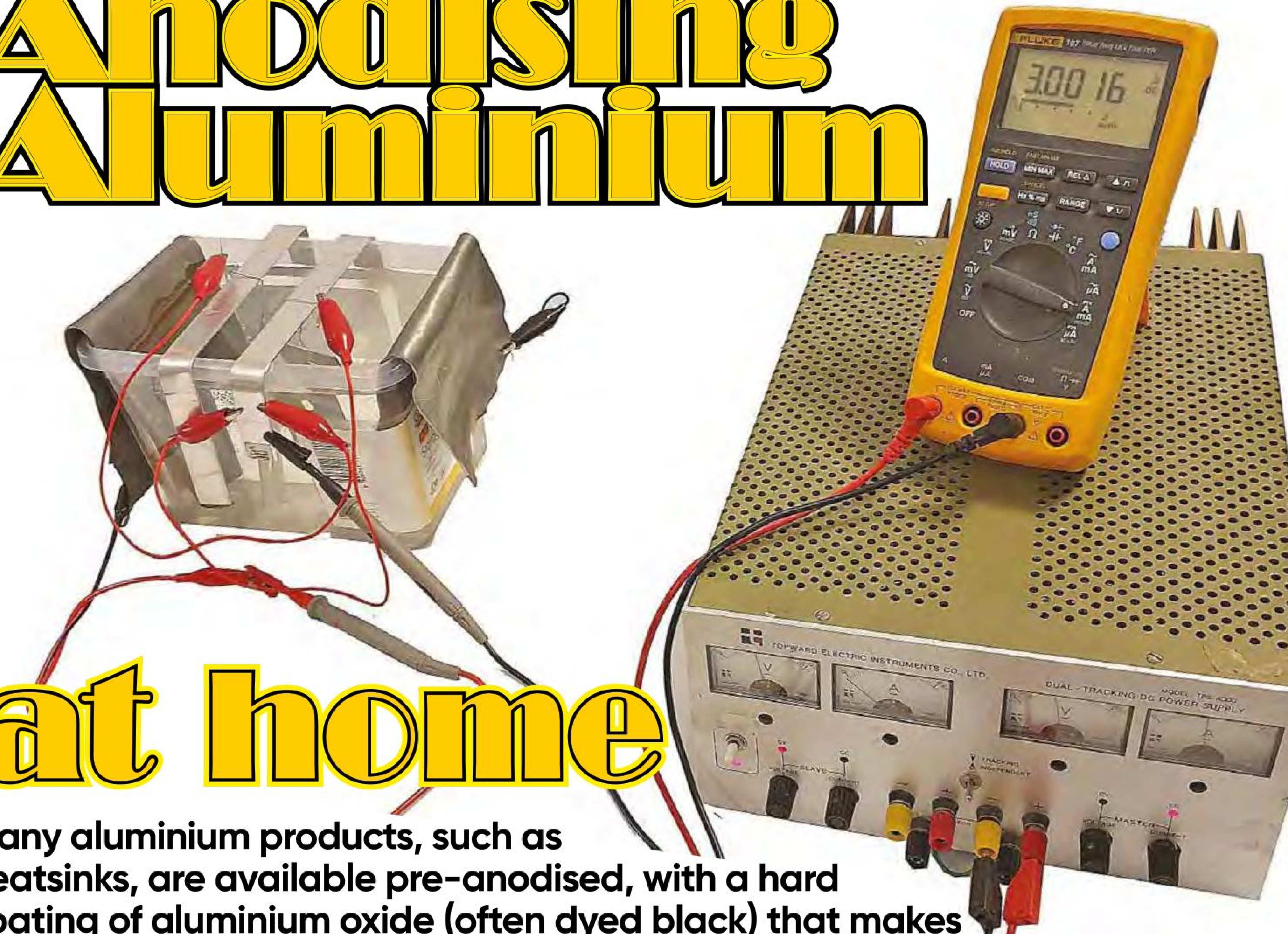
Anodising Aluminium at home



Many aluminium products, such as heatsinks, are available pre-anodised, with a hard coating of aluminium oxide (often dyed black) that makes the surface considerably tougher. But sometimes parts are supplied in 'raw' aluminium. What if you'd like them anodised? As it turns out, as long as you take due care (especially with the chemicals used), it isn't that hard to do it yourself.

by Phil Prosser

We are all familiar with aluminium. It is a very common metal that is seen in all aspects of our lives, from structures through to household goods like drink cans and of course in electronic systems. After all, aluminium is the most abundant metallic element in the Earth's crust.

Aluminium was not isolated as a metal until 1824, and not industrially produced until the mid-1800s. The primary difficulty was that efficient refinement of aluminium ore to metal requires electrolysis at very high temperatures and uses a great deal of electrical energy, which was not available back then.

So common industrial use of aluminium did not commence until well into the 1900s. Read up on the Hall–Héroult process if you are interested.

Why anodise?

As hobbyists, aluminium is a 'go-to' material due to its easy workability, ductility, low weight and low cost.

But it is often not clear how to finish the aluminium that you use. Many commercial products have an anodised finish, which is easily recognised by the very thin, very hard and often coloured finish.

The main benefit of anodising aluminium is that it significantly increases the metal's corrosion resistance

When you cut or otherwise expose raw aluminium, it very quickly oxidises and forms a layer of aluminium oxide (Al_2O_3) on the surface. This actually forms part of the surface and is effective protection for the underlying reactive material. Still, it is very thin, easily damaged and is not sufficient to protect the metal in corrosive environments or over long periods.

Safety first

Anodising aluminium is fun, practical and a great way to add some pizazz to your projects' housings and enclosures or any other metalwork you are using. BUT, you must follow all safety warnings and always be aware of other people around you, especially children, and also pets. Never assume they understand the dangers!

For industrial applications, aluminium surface protection cannot be left to chance. The anodising process is often used to artificially grow a thick layer of aluminium oxide on the metal surface.

This provides excellent corrosion resistance and provides an extremely hard protective layer to the metal.

The structure of aluminium oxide in the anodised layer also provides the ability to bind dyes, which is how many anodised surfaces are coloured

Doing it yourself

In this article, I will describe how you can anodise and dye your own parts at home, resulting in much more durable and attractive products.

For feature parts and modestly-sized items, anodising at home is a practical option. Very attractive results can be achieved without undue effort.

Some specialised applications require 'hard anodisation' which creates a thick, hard oxide layer aimed at providing wear resistance.

Standard anodisation creates an oxide layer up to 30 microns thick, while hard anodisation can create a layer up to 100 microns. But this involves refrigeration and much higher voltages; while you probably could do it at home, it isn't as easy, so I won't describe that here.

The goal of this article is to describe the regular anodisation process, which provides corrosion resistance and the ability to apply decorative finishes.

What can I anodise?

It isn't just aluminium that can be anodised. Other suitable metals include magnesium, titanium, tantalum and zinc. But we'll focus on aluminium as it is commonly available, easy to work and the process for anodising it is not complicated.

As you will see in this article, anodising falls somewhere between DIY electronics and chemistry. I will walk you through the following five steps:

- **Cleaning**
- **Pre-anodisation etching**
- **Anodising**
- **Dyeing**
- **Sealing**

We will also walk through the set-up of the etching bath, anodising bath and provide some guidance on how much current you should be using to anodise your parts and for how long.

Safety

Before we start, let's discuss safety. Anodising requires the use of both a strong acid and a strong base. It is essential to understand the hazards of working with these chemicals, and to know how to manage the risks involved.

Anodising aluminium uses two common but nevertheless nasty chemicals, sulphuric acid and sodium hydroxide.

Sulphuric acid is a hazardous chemical. In the concentrations we need, it is corrosive to eyes, respiratory system and skin. It will quickly eat through clothing and unprotected

What you need

Item	Source	Comment
Safety glasses	Any hardware store	*Buy a pair that wraps around your face.*
Nitrile gloves	Hardware store, supermarket	*Buy a large box of disposable gloves.*
Power Supply	Your workshop	*Ideally 3-30V at 1-6A (depending on job size).*
Clip leads	Your workshop	*Acid will corrode your clips! Wash them or use old leads.*
Anodising tank	Hardware store, supermarket	*A plastic tank just large enough to hold your workpieces – food containers or plastic pails are suitable.*
Lead Sheet	Hardware store	*This is sold as lead flashing. It is expensive.*
Sulphuric acid (H_2SO_4)	Battery or car accessory shops	*Acid is not on the shelf; you need to talk to staff. Expect to pay about £5 per litre.*
Sodium bisulphate ($NaHSO_4$)	Hardware store or pool shop	*Alternative to sulphuric acid; often sold as pool pH dropper*
Safety container		*Slightly larger than your acid bottle, to contain any leaks.*
Rinsing container		*Larger than your parts, kept full of clean water for rinsing off after etching, anodising and staining.*
Dyes	Lincraft, eBay	*Clothes dyes or anodising dyes.*
Sodium bicarbonate	Supermarket	*1kg containers are cheap; buy several, keep at hand if you need it to neutralise spilled acid. Also called 'bicarb soda'.*
Acetone	Hardware store	*Used for cleaning oil off parts before etching.*
Deionised/distilled water	Supermarket, auto shops	*Tap water can be used, but this is better.*
TIG aluminium wire	Hardware store	*Or strip out of cabling.*

TGC NITRILE GLOVES BLACK
Protector
Safety Goggle
Impact | Chemical | Dust
when safety matters
SULPHURIC ACID
CORROSIVE
coles
bi-carb soda

We cannot emphasise enough the need for safety equipment and all care. Some of the chemicals used for anodising are pretty nasty and can cause damage or injury if you're not careful. You should also store chemicals with a second container which will catch any spills before they have a chance to do damage (known as 'bunding', as seen at centre above). Bicarbonate of Soda (often abbreviated to simply Bicarb Soda) is readily available in supermarkets as it is used extensively in cooking –see right.

surfaces. You can download a PDF material safety data sheet (MSDS) from: **https://bit.ly/pe-nov23-sa**

The etching process uses a 2% mixture of sodium hydroxide, which is a caustic base, and quite harmful to skin and eyes. Download a PDF of its MSDS from: **https://bit.ly/pe-nov23-naoh**

I recommend that you use the 'take 5' approach before any operation using the chemicals in this article:

1) **STOP** before starting each activity. Consider all aspects of this, including your preparedness.
2) **THINK** through what you need to achieve and consider what might go wrong or cause a problem.
3) **IDENTIFY** potential hazards to yourself, others and the environment around you. What is the potential risk?
4) **PLAN** how to undertake the activity while minimising hazards. Have contingencies for spills.
5) **PROCEED**

So why do we need acid?

It turns out that sulphuric acid is an extremely useful reagent and a chemical that is found in many industrial processes and parts of everyday life. It is produced and used in large quantities all around the world. While sulphuric acid has primarily industrial uses, it's also found in everyday household products such as drain cleaner and fertiliser.

You should obtain and read the safety data sheets (linked above) for sulphuric acid, sodium hydroxide and, if you use it, sodium bisulphate (**https://bit.ly/pe-nov23-sbs**) before starting. Without seeking to replicate the safety data sheets, key messages are:

- **Skin contact –** if sulphuric acid comes into contact with your skin, immediately flush the affected area gently with lukewarm water for at least 30 uninterrupted minutes. **Seek medical attention immediately**.

- **Eye contact –** if sulphuric acid gets into your eyes, immediately flush the eye(s) with water for at least 30 minutes. **Seek medical attention immediately.**

- **Ingestion –** if you ingest sulphuric acid, rinse your mouth immediately with water. Do not induce vomiting. Continually rinse your mouth with water and **seek medical attention as soon as possible.**

- **Inhalation –** if you inhale sulphuric acid aerosols, **seek fresh air and medical attention immediately.**

- **Spills –** if you spill acid, first check that none got onto you or others. If so, deal with that first. Small quantities of sulphuric acid can be neutralised using sodium bicarbonate, which once neutralised, can be cleaned up and disposed of.

Personal protective equipment (PPE) is required. The recommendation for working with these chemicals includes:

- **Wrap-around eyeglasses**
- **Nitrile gloves**, which you change every time you touch acid or base containing vessels
- **Overalls**, or clothing you don't mind getting a few holes in
- **Always** wash your hands after moving from the work area

Pro safety tip:

Always store acid in a 'bunded' area, so if there is a failure of your acid container, the spill is caught in the bunding. We do this by merely placing the acid container inside a slightly larger container.

We trust that at this point, you have informed yourself of the materials with which we are working and established a safe work area. Let's get into the process.

Just what is happening?

Fear not; this is as much chemistry as I will go into. Because anodising aluminium is an electrochemical process, we need to consider what happens at the anode (which is the workpiece) and the cathode in the reaction. Fig.1 shows the generalarrangement.

At the anode: $2Al + 3H_2O \Rightarrow Al_2O_3 + 6H^+ + 6e^-$
At the cathode: $6H^+ + 6e^- \Rightarrow 3H_2$
Resulting anodising reaction: $2Al + 3H_2O \Rightarrow Al_2O_3 + 3H_2$

The Al_2O_3 is a conversion of the aluminium on the surface of the workpiece. Hydrogen gas (H_2) is generated at the cathode, and can be seen as bubbles – so definitely no smoking anywhere in the area and care must be taken to eliminate electrical sparks.

The electrolyte, generally sulphuric acid, is not consumed in the anodising reaction. So the acid bath can be reused many times.

Anodisation actually converts a very thin part of the surface of your workpiece into aluminium oxide. The process described in this article produces a 25-50 micron layer, which usually leads to an insignificant change in thickness.

The way that aluminium oxide grows on the surface of the part creates a hexagonal, honeycomb-like structure. The

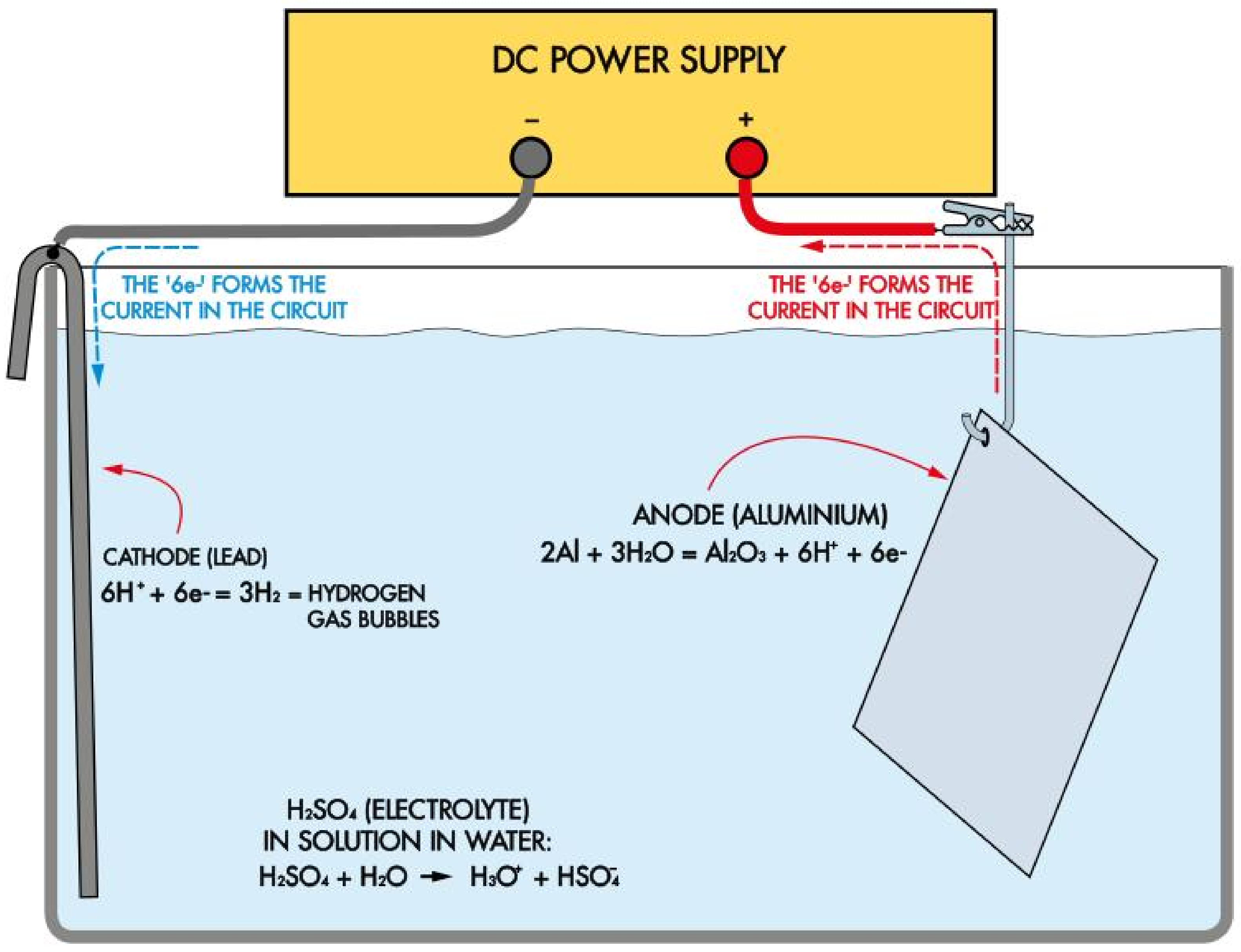

DC POWER SUPPLY
–
+
THE '6e-' FORMS THE CURRENT IN THE CIRCUIT
THE '6e-' FORMS THE CURRENT IN THE CIRCUIT
CATHODE (LEAD)
6H+ + 6e- = 3H2 = HYDROGEN GAS BUBBLES
ANODE (ALUMINIUM)
2Al + 3H2O = Al2O3 + 6H+ + 6e-
H2SO4 (ELECTROLYTE)
IN SOLUTION IN WATER:
H2SO4 + H2O → H3O+ + HSO4-

Fig.1: the basic arrangement for anodising aluminium. The part to be anodised connects to the power supply +, while the lead cathode connects to the power supply –.

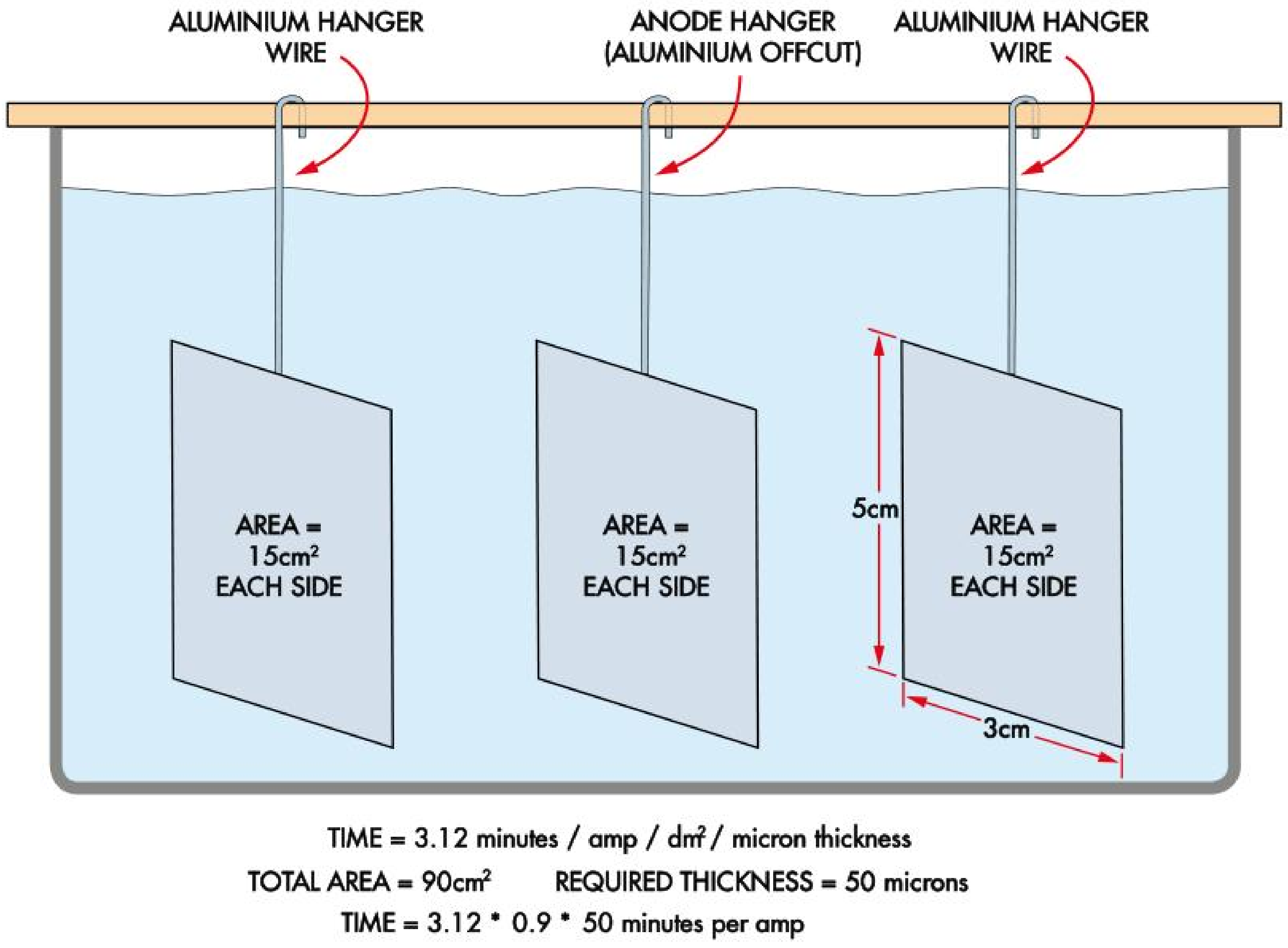

ALUMINIUM HANGER WIRE
ANODE HANGER (ALUMINIUM OFFCUT)
ALUMINIUM HANGER WIRE
AREA = 15cm² EACH SIDE
AREA = 15cm² EACH SIDE
AREA = 15cm² EACH SIDE
5cm
3cm
TIME = 3.12 minutes / amp / dm² / micron thickness
TOTAL AREA = 90cm²
REQUIRED THICKNESS = 50 microns
TIME = 3.12 * 0.9 * 50 minutes per amp

Fig.2: you can anodise several pieces at once like this. Add up the total surface area (include both sides!) to calculate the required time and current.

structure is tiny, but large enough for dyes to be captured within. So once we have anodised a part, we can take advantage of this structure and use it to hold coloured dyes.

Anodising time

We have just seen that anodising is a chemical conversion of the part, driven by an external power source. So how much current is required and for how long?

The current at which you anodise has several impacts on the type of finish you get. This is a variable that you will need to experiment with. I'll provide some rules of thumb, and the results of my experience as a starting point:

- Lower temperatures and higher voltages (to achieve the required current) can lead to very thick finishes
- The type of aluminium alloy present, and any impurities, has an impact on the result
- The thickness of anodisation layer is largely a function of how long you anodise
- If you use a voltage source rather than current source, the current will vary throughout the process

Remember that anodising is all about a chemical reaction, and the current the process draws is a result of the chemical reaction moving ions around. So controlling the current is much preferable to the voltage, as this gives you some control of the chemical process.

One common rule often used to determine the current required is 'the rule of 720', where:

$$\text{minutes to anodise} = \frac{\text{thickness of desired layer in mils} \times 720}{\text{amps/ft}^2}$$

Converting this to metric units gives us the rule of 3.12 (almost pi, but not quite!):

$$\text{minutes to anodise} = \frac{\text{thickness of desired layer in microns} \times 3.12}{\text{amps/dm}^2}$$

Yes, we are using the decimetre (dm) as a unit. One square decimetre is 100cm^2, eg, 10x10cm.

One of my tests used three pieces of aluminium of 30cm^2 each (see Fig.2). So we had a total of 90cm^2 or 0.9dm.

I wanted a 50 micron thick coating, so the calculation was:

$$\text{minutes to anodise} = \frac{50 \times 3.12}{(\text{amps} \div 0.9)}$$

This works out to 140 minutes (50 x 3.12 / 0.9) / amps.

Try to keep the anodising current in the region of 1-3A per 100cm^2, if for no other reason, doing this will give you a reasonable time to anodise the part to a 20-50 micron thickness.

You will note that for large parts, this might require a very high current source.

I have not tried anodising whole rack cases, but if your power supply cannot deliver the required current, you just need to anodise at the highest available current setting and let it run for as long as required.

The process – a workflow

Fig.3 shows a basic workflow for anodising, with the steps you will need. They are described in more detail below. There are many variables, especially in the parts you wish to anodise and the equipment you have available.

The steps include preparation, setting up the anodising, staining and sealing. I suggest that you start at a small scale and run some test pieces before ramping up to large parts.

Remember that large parts will require large baths and power supplies.

Anodising bath electrolyte

While it is not commonly used, it is possible to anodise using sodium bisulphate as the electrolyte instead of sulphuric acid. I ran several tests using sodium bisulphate and got identical results.

There is not a lot of discussion on the internet about this alternative. Some commenters suggested that the chemical bath may need to be replaced regularly, as opposed to sulphuric acid, where the same bath can be kept and used many times.

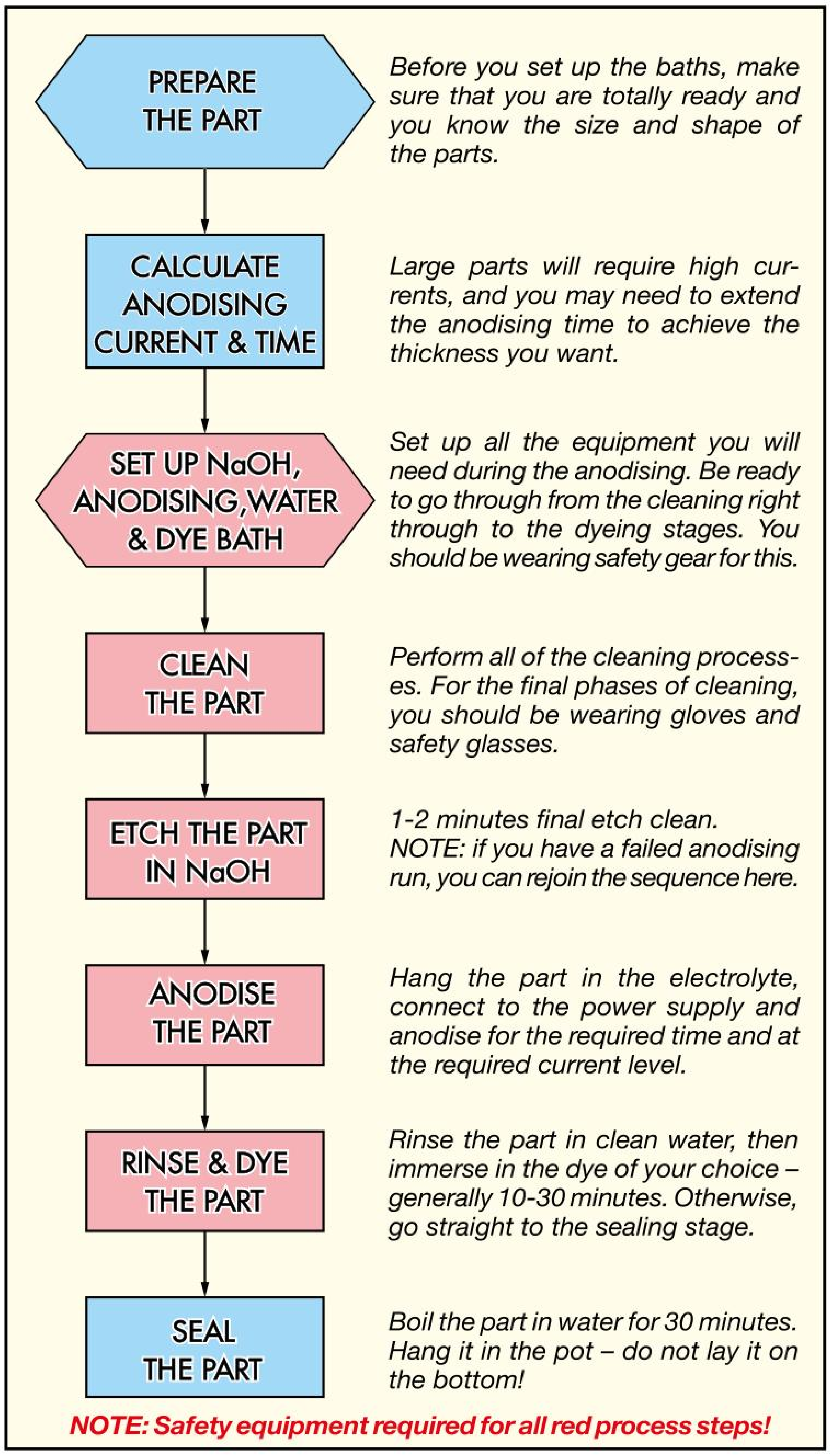
I suspect that they may have a point, but for the few tests I ran, it gave perfect results.

If you are having trouble finding sulphuric acid and only wish to run a few experiments, then this is a real option as the materials are available at your local pool or hardware store.

Sodium bisulphate is inexpensive, and if you are not planning to set up a factory, the possible short lifespan of the electrolyte bath is not a big deal.

Electrolyte preparation steps – sulphuric acid

1) Purchase standard battery acid. I bought some with an SG of 1.28, or about 36% concentration, and diluted it to between 10-15% concentration. **Add acid to water!**



Before you set up the baths, make sure that you are totally ready and you know the size and shape of the parts.

Large parts will require high currents, and you may need to extend the anodising time to achieve the thickness you want.

Set up all the equipment you will need during the anodising. Be ready to go through from the cleaning right through to the dyeing stages. You should be wearing safety gear for this.

Perform all of the cleaning processes. For the final phases of cleaning, you should be wearing gloves and safety glasses.

1-2 minutes final etch clean.
NOTE: if you have a failed anodising run, you can rejoin the sequence here.

Hang the part in the electrolyte, connect to the power supply and anodise for the required time and at the required current level.

Rinse the part in clean water, then immerse in the dye of your choice – generally 10-30 minutes. Otherwise, go straight to the sealing stage.

Boil the part in water for 30 minutes. Hang it in the pot – do not lay it on the bottom!

NOTE: Safety equipment required for all red process steps!

Fig.3: a flow chart which explains all the steps required in anodising. It is not absolutely essential to dye the part, nor even to seal it – but it will be much tougher if you do! Note the comment regarding safety equipment: it's for YOUR protection!

2) Select your anodising bath container. Make sure it is much deeper than your part, can be carried easily and emptied easily.
3) Fill to two thirds of the final bath depth with deionised/distilled water.
4) Then (and this is the last time I will mention this) wearing your personal protective equipment, add acid to the water, filling the bath to the final depth. NEVER add water to acid, as this can lead to the water boiling and splashing!

Electrolyte preparation – sodium bisulphate

The steps are the same as above, but you need to add 20% by weight of sodium bisulphate crystals to the water for the solution you need. So if you want 5L of electrolyte, add 1kg of sodium bisulphate crystals to 4L of water. Note though that this will give you a little less than 5L – to be honest, I cut a corner and just used a little extra water to make it up.

We found the crystals took ages to dissolve. They eventually did, though. We noticed that the sodium bisulphate bath was less clear than the sulphuric acid bath. I suspect that this is because the purity of pool chemicals is not great, while battery acid usually is very well controlled.

CAUTION
DIGGERS
acetone
1 Litre

Acetone is used to clean the parts to be anodised of any oily residue. It is readily available at hardware stores.

HY-CLOR
pH
Decreaser
(Dry Acid)

Sodium Bisulfate, an alternative to Sulphuric Acid, is also readily available – a good source is your local pool shop, where it is sold as pH Decreaser.

The bath was somewhat cloudy, though over several batches of anodising, it did clear up a bit. Your experience may be different.

Note that when using sodium bisulphate, you're likely to get sodium sulphate generated and deposited at the cathode. So you may need to clean the cathode after a few runs or else you might find that you have to apply a higher and higher voltage to get sufficient current flow.

Cathode preparation

The cathodes can be either aluminium or lead. Aluminium will not last, but lead can be tricky to find in small pieces. Digging around in the back of an old shed usually unearths a few sheets of lead, which is commonly used for flashing on roofs. You may also be able to get your hands on lead curtain weights without spending much.

You will know when you find it, as it is heavy, very ductile and often crusty looking if it is old. That is OK, a good scrub with a scourer will make it ready to use. The cathode surface area should be approximately the same as the area of your workpiece, although that is not critical.

If you want to buy some lead, it is available from hardware stores, but you may be forced to buy more than you want, and it is not cheap.

A friendly chat with your local plumber might be a cost-effective alternative, especially if facilitated with a six-pack of your plumber's favourite beverage.

I simply cut and bent the lead sheet to fit my container. Make sure your connection to the cathode is outside the electrolyte, or your leads will very quickly become corroded, and may contaminate your acid bath.

Even though it gets 'dirty', the cathode is not used up in this reaction, so it can be reused many times.

As noted above, if lead is too much of a hassle, heavy aluminium foil such as you find on takeaway containers also works.

I used this in my first tests without a problem. Should you happen to have a stash of titanium sheet, this would be ideal.

Unfortunately, my personal jet fighter needs all of its titanium bits!

As you may have guessed, the cathode will eventually connect to the negative end of your DC power supply.

Part preparation

Preparation is absolutely everything in terms of the finish you achieve on your parts. Anodising produces a micron-scale later of aluminium oxide, which will do nothing to hide a scratch or dent. Dyeing the part simply changes the colour, and does nothing to fill defects or blemishes. If you spend five minutes preparing the part, you will be able to tell at the end!

You won't need a whole roll of lead – it's quite expensive so if you can beg or borrow a smaller quantity (maybe a local builder or plumber?) you will be better off!

ALUMINIUM
M
WELDING WIRE
MIG
0.9MM
BOSSWELD

Aluminium wire is commonly available at better hardware stores – it is sold as 'Tig' welding wire.

That said, if you are restoring an old vehicle and want to anodise old aluminium parts that you have cleaned up, plain anodising will certainly protect that part from the elements and ensure that all your hard work lasts. There are a few steps to prepare your parts for anodising:

1) Make the parts (if not already made)
2) Prepare the surface
3) Scrub clean
4) Clean of oil and finger grease
5) Etch the surface to remove any residual anodising

We'll go through these briefly.

Manufacturing the parts

If you are making the parts yourself, it is a good idea to make sure there is a conveniently located hole that can be used to hang the part during the anodising process.

For the demonstration parts, I simply drilled a small hole in the corner. But you might not have that luxury with your part!

It is imperative that there is good electrical contact between the hanging wire and your part.

One option that we've taken in the past is to drill a hanger hole in a spot that will be hidden from sight in the final application, and make 'paper clip' type hooks from aluminium wire to feed through that hole and hang the part in the bath.

Surface preparation

The first level of preparation is to ensure the surface is free of scratches and dents. This starts when manufacturing your part. Just as if you were planning on painting the surface, use material that is free of scratches and dents, be careful how you mark it up and do not leave tool marks on the part.

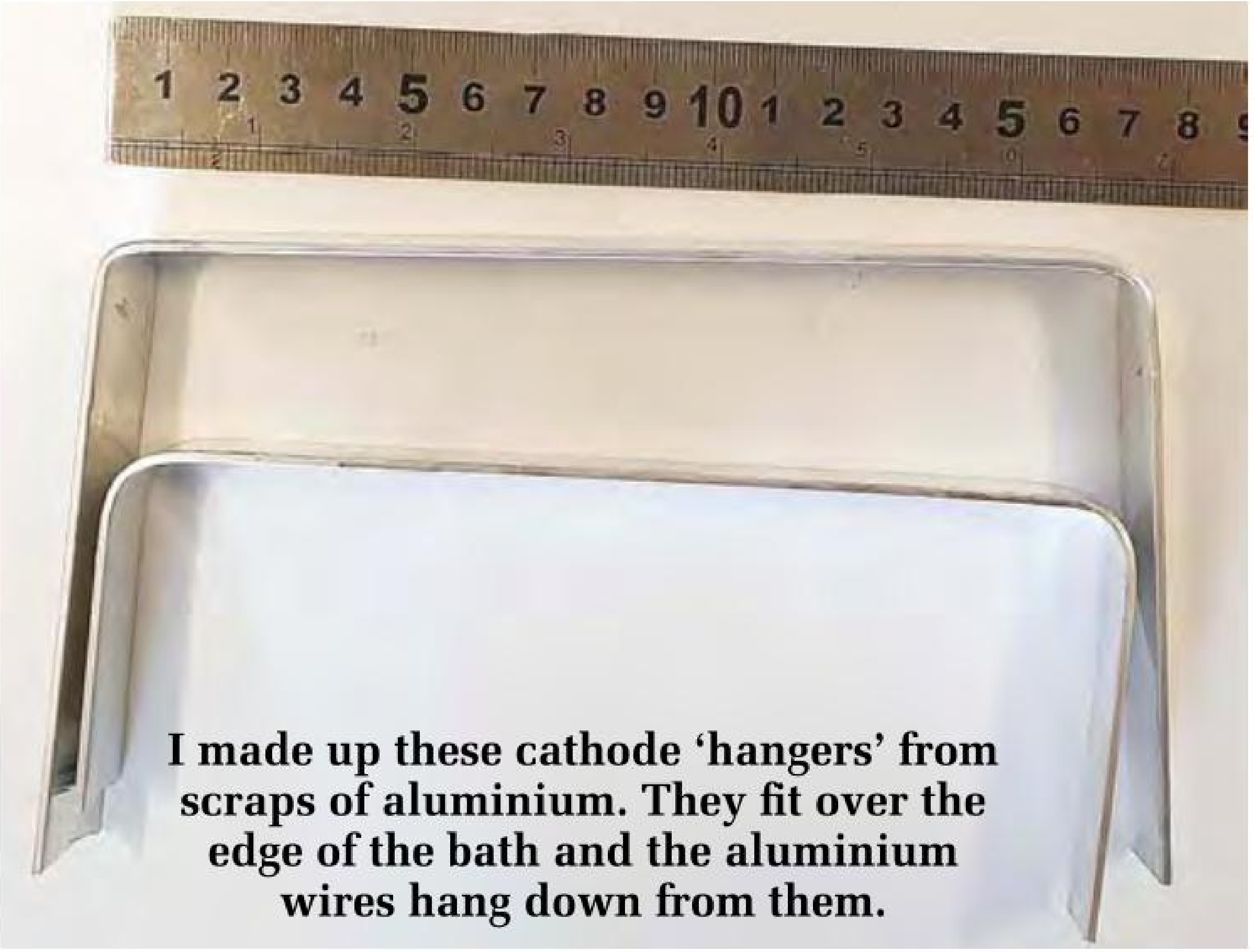
Finishing your edges requires either clean cuts (for example, using a guillotine), or you need to file and sand the edges smooth.

When filing, remember that you need to work from a coarse to a fine file, and probably will want to end with sandpaper to get a clean edge.

Scrub clean

Once your parts are made and finished to your satisfaction, they need to be cleaned of any surface contamination. Unless the surfaces are freshly machined (ie, you have just taken the part off a lathe or milling machine), you will need to clean the surface very thoroughly, including scrubbing off any existing anodisation layer on the surface.

This is generally done by taking a green scouring pad or fine sandpaper to the surface and scrubbing away any sign of anodisation, oil or other surface contamination. This needs to be a very vigorous process and should leave you with an immaculate and shiny part.



I made up these cathode 'hangers' from scraps of aluminium. They fit over the edge of the bath and the aluminium wires hang down from them.

Work from say 400 grit wet and dry sandpaper through to 800 or even 1200 grit. The surfaces I finished with 1200 grit came out very smooth and clean looking. You need to be careful to sand in straight lines and not leave scuffs on the surface.

Using wet and dry paper under running water assists with keeping the paper clean.

Clean away oil and finger grease

At this point, you need to glove up. This time, it is to keep you from contaminating the part with oil from your fingers.

Any oil deposited from here on will interfere with the anodising process. In one of my tests, I touched a part and once it was stained, it was obvious where it had been touched.

Clean the part(s) first with soapy water, then with acetone, by wetting a tissue with acetone and wiping the part down.

Use acetone in a reasonably ventilated area, and dispose of the tissues with care, as it is flammable. Once cleaned, attach your connection wire.

As discussed above, having a cleverly placed hole that you can squish the wire into helps. Do this with your gloves on, and make sure the connection is solid.

Making the anode connection

To make your part an anode, you need to attach a piece of aluminium wire. Why use aluminium wire? If you put steel or copper into the bath, the electrolytic process will eat these away very quickly, and in the process likely cause the anodisation to fail.

The surface finish on your parts before anodising will determine how they come out. Once anodised the surface finish is protected by the hard anodised layer. Spend that extra five minutes before anodising to get them perfect.

Lead makes a great cathode. Lead sheet is not pretty, especially after use, but that is fine – you can use it over and over again.
(Right): these are some scrap pieces I used for trialling my anodising processes and chemistry. It's always wise to do many trials on offcuts and scraps to get timing and chemicals correct before the 'real thing'.

By using aluminium wire, this is avoided, and the only effect is that **the hanger wire is anodised in the process.**

Aluminium wire is available as TIG welding wire from a hardware store (I patronised my local Bunnings). It will probably be hidden away in the tools section. Alternatively, if you have some heavy-duty power line cables laying around, they might use aluminium wire internally, so this could be a cheap source.

Ideally, the hole in your part should be just the right size to poke the TIG wire into, with a tight fit. I used a 0.8mm PCB drill for this, and squished the TIG wire so that it was tight in this hole. Alternatively, you could fold the wire over and push it into a screw hole.

Professional anodising systems use aluminium or titanium hangers which incorporate clips that firmly grip the part.

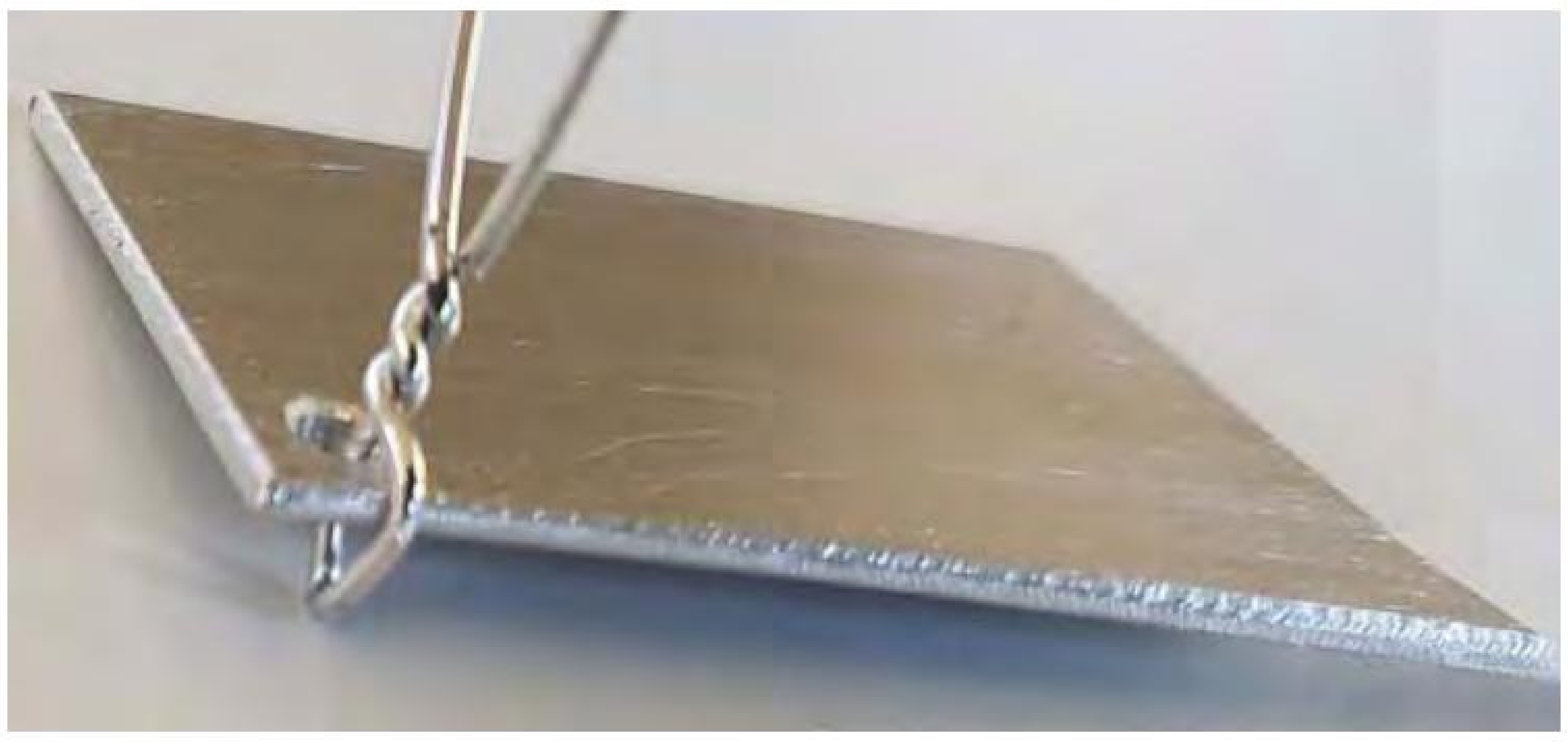
Etching the part surface

Place the part in the sodium hydroxide bath for 1-2 minutes to remove any remaining oxide layer. To prepare this bath, make a solution of 2% sodium hydroxide with clean water. That is about two spoons of pure NaOH per 500mL of water.

Keep your gloves and glasses on during this process.

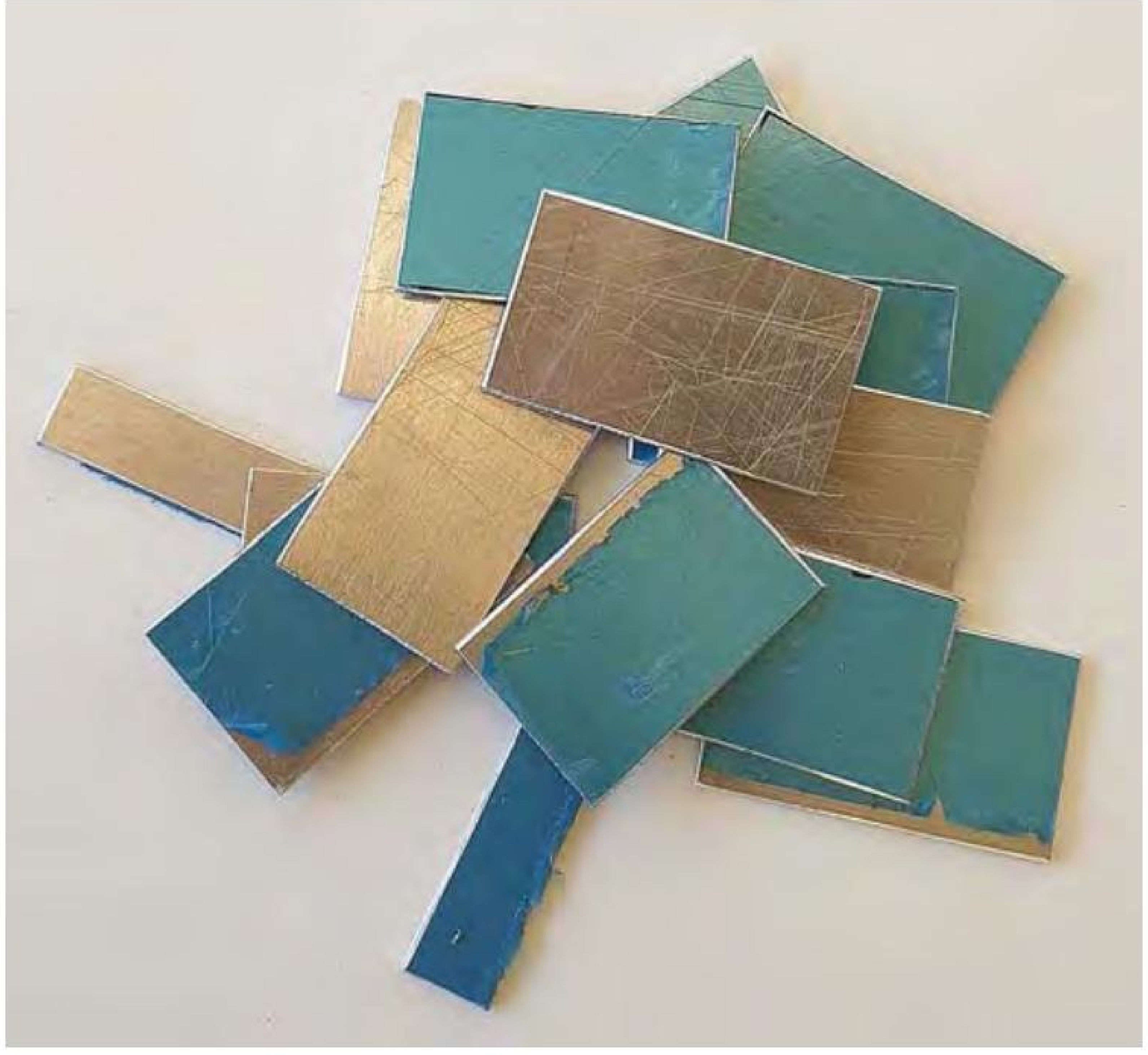
Hold your part by the attached anode wire; do not put your fingers in the solution even with gloves on. By one minute, your parts should be fizzing away happily, and by two minutes, you can pull them out and move them to a clean water bath.

This water bath removes any residual sodium hydroxide before the part goes into the anodising bath.



Achieving good electrical connection to your parts is essential. It is also not as easy as it might seem. Our main cause of problems was poor connection at the anode.

At right: we made up these 'hangers' to support small pieces of work – the idea is to keep these out of the solution so they don't get anodised!



Anodising

You are now ready to anodise your parts. You should have your anodising bath ready, with the cathode plate in and connected to your power supply, and a hanger of some sort that allows you to hang your parts in the bath. The bath should already contain the electrolyte.

Take your parts from the clean water bath and bend the hanger wire to allow them to hang in the anodising bath without touching the cathode or each other.

When hanging the parts, wear all your protective equipment. Do not put your hands in the electrolyte, even though you have gloves on.

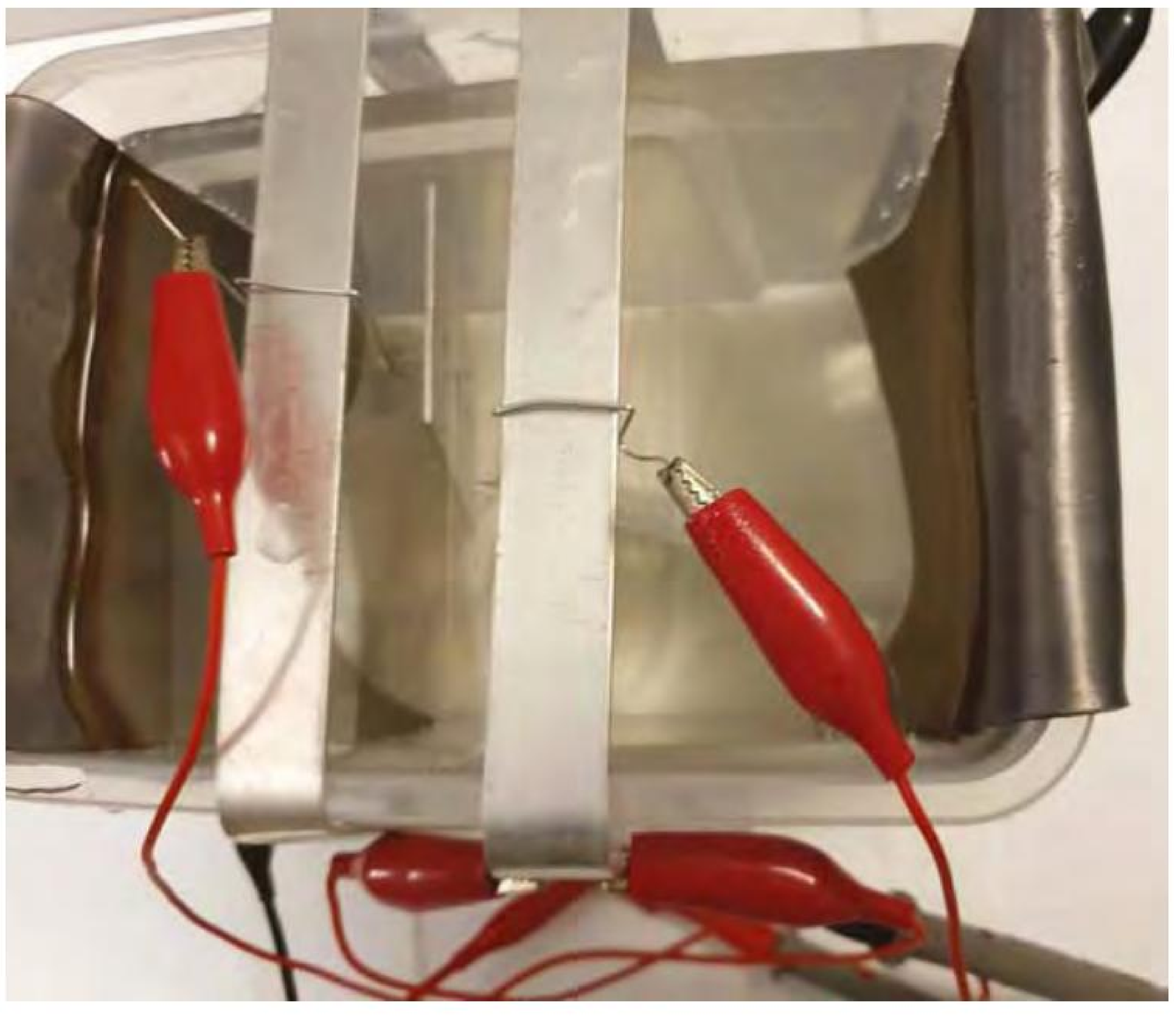
If you drop a part, use timber tweezers or similar to fish it out and then clean it off in water and start again.

Use clip leads to make sure that there is an electrical connection from the positive supply to the anode connection on your part. This might save you from using bad language later on!

Apply power and set the current to your desired level.

To check that there is a good connection to all your parts, take a clip lead off each one and ensure that the supply voltage changes (or current, if you are using a constant voltage power supply).

The anodising process will take quite a while. My test case took two hours. Most practical runs should be in the 1-2 hour range, possibly more if your parts are substantial.



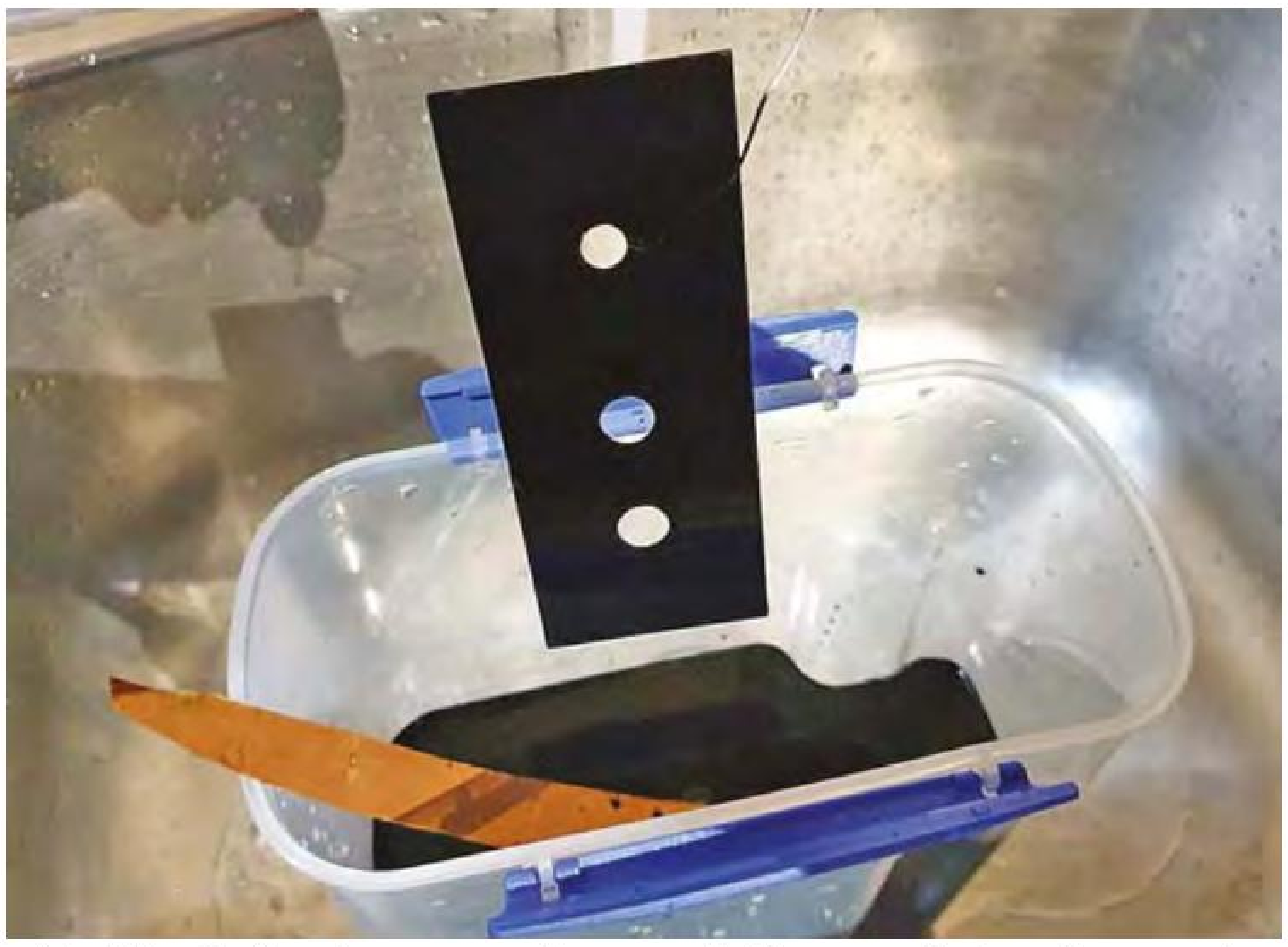
Check from time to time that everything looks OK. Remember to put your glasses and gloves on every time you go near to the bath. Be prepared to dispose of a fair few pairs of gloves.

When the time is up, fish your parts out using tweezers and put them in a clean water bath. There will be a subtly grey finish to the parts. This is the raw anodised layer. They are then ready for staining and sealing.

2%
NA OH
CLEAN
WATER

Arranging your workspace is important. This shows how we lined up etch and rinse baths to support a simple workflow.

This tub of green dye works particularly well. This is after a very brief dip – and shows that we had not properly mixed the powder in. Preparation is important.



This black dyed part used a specialist anodising dye, and worked extremely well – much better than some of the RIT fabric dyes (see the table below).

Staining

To stain the parts, hang them in a stain bath. The time required depends on how dark you want the colour to come out and on the dye itself. In preparing this article, I tried out quite a few different dyes with mixed success. The most consistent outcomes were found with dyes sold especially for staining anodised surfaces.

I also had success with some (but not all) of the RIT dyes which are sold for colouring fabric.

Take a look at the photos to see a few of my test pieces.

Generally, 5-20 minutes is enough to stain parts. Note that the sealing process takes away a little of the colour depth.

If something went wrong in the anodising process (most likely due to a power supply connection problem), that part will not take any colour in the dyeing process. This is because the aluminium oxide microstructure is not there to hold the dye.

Sealing the parts

This simply involves immersing them in boiling water for 30 minutes. This seals off the top of the cells in the aluminium oxide and holds the dye in place. If you aren't dying the parts, you still need to seal off the top of the cells.

Use an old pot with a lid. I bought mine at a local op shop for a couple of dollars. Some dye is released during this process, and it's best not stain the expensive kitchenware.

Results and conclusions

I ran several test runs on some small pieces of aluminium to test out the process and a range of dyes. I found that the process worked well with both sulphuric acid and sodium bisulfate as the electrolyte.

Of the dyes I tested, many of them gave excellent colours. It is clear that anodising and staining can deliver both protective and decorative results.

With appropriate care and preparation, the process is safe and straightforward.

At left is my evaluation of the range of dyes tested, which are available from eBay and in your local store.

I have included some photos of the results of our tests, to show you the sort of colours you can achieve. You will see some scratches on these – that's because I was still learning some of the tricks that I have now passed on to you!

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Dye	**Result**
Classic Plating Green (eBay)	*Very effective (specialised anodising dye)*
Classic Plating Black (eBay)	*Very effective (specialised anodising dye)*
RIT Tangerine powder	*Worked a treat*
RIT Denim Blue powder	*Very inconsistent and patchy result although this was a powder dye; might work better as a liquid.*
RIT Royal Blue liquid	*Worked OK*
RIT Scarlet Red liquid	*Worked well*
DYLON Velvet Black (Coles)	*Total failure*

Some dyes give a better result than others – and some are pretty hopeless! It really is a matter of trial and error (more errors than trials?).

Max's Cool Beans

By Max the Magnificent

Arduino Bootcamp – Part 11

Hello there. I hope you're having as much fun as I wish I was having. I'm currently cursing myself for a fool because we closed my previous column (*PE*, October 2023) with me giving you some homework projects. Not that there's anything wrong with that, *per se*. The more, the merrier, if anything. The problem is that I foolishly said: 'We'll compare results when next we meet,' which means I must also do these projects myself. Rats!

Building the excitement

Before we plunge into the fray with gusto and abandon (and aplomb, of course), let's briefly discuss what we're going to do in this column and our next column, in addition to completing our previous column's homework assignments.

In the context of our discussions here, we understand sensors to be devices that produce output signals (voltages or currents) corresponding to physical phenomena in the real world (light, heat, humidity, motion, pressure…). We can feed these signals into a microcontroller unit (MCU) like the Arduino Uno we've been using for our experiments, and then use them as the basis for decisions and actions.

Speaking of actions, actuators are devices that produce some form of motion (rotary or linear) that can be used to move and control a mechanism or system – for example, opening a valve. Actuators can be electric (eg, various flavours of motors), hydraulic, pneumatic, piezoelectric, magnetic… the list goes on. When we come to think about it, it becomes apparent that our piezoelectric buzzer is a simple form of actuator, as is any loudspeaker.

Also, we have display devices, which can be as simple as a single light-emitting diode (LED), slightly more complicated like our 7-segment display, all the way up to mindboggling holographic displays. (As I always say, 'Show me a flashing LED, and I'll show you a man drooling.')

In previous columns we've experimented with simple sensors in the form of pushbutton switches and potentiometers. What we are poised to do in our next column is add sensors to detect ambient light and distance. In addition to controlling the frequency of our piezoelectric buzzer, we are going to use the values from our sensors to control various aspects of our 7-segment display device, including the frequency of a flashing segment, the value being displayed, and the intensity (brightness) of the display.

The terms 'gazintas' (or 'gazins') and 'gazoutas' (or 'gazouts') are humorous pronunciation spellings of 'goes into' and 'goes out of,' respectively. Bearing this in mind, we can summarise the contents of this column and our next as illustrated in Fig.1.

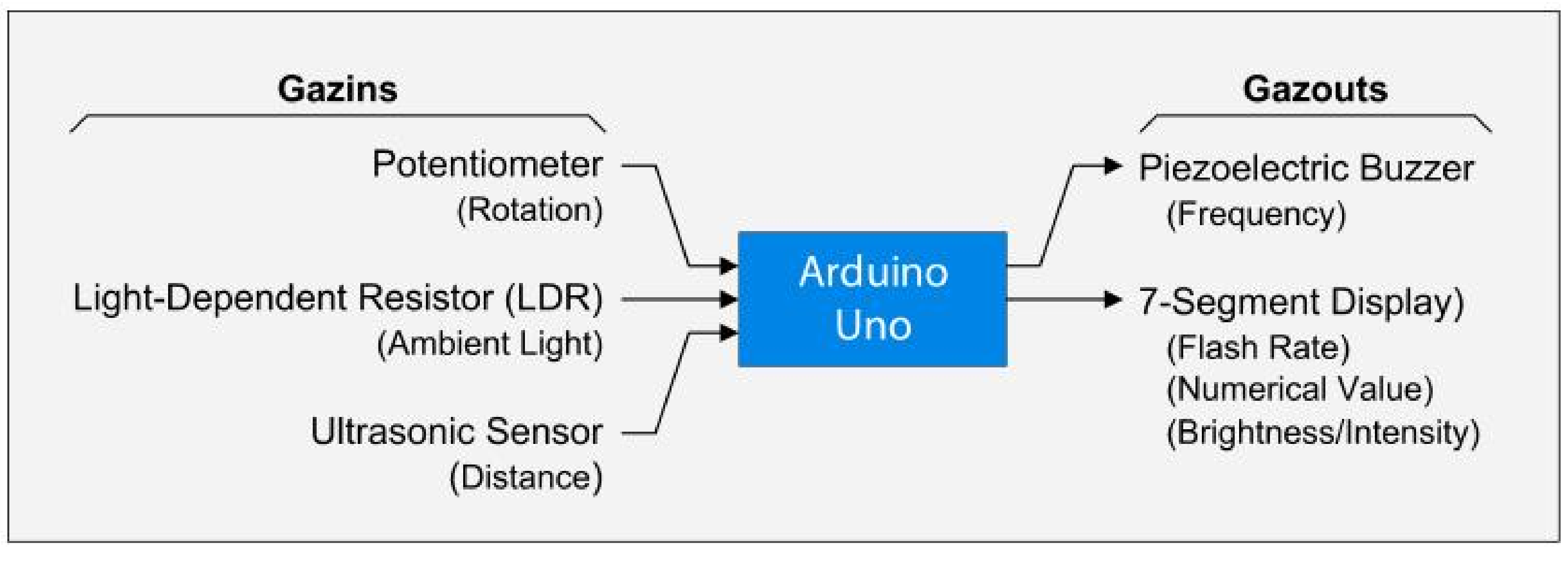
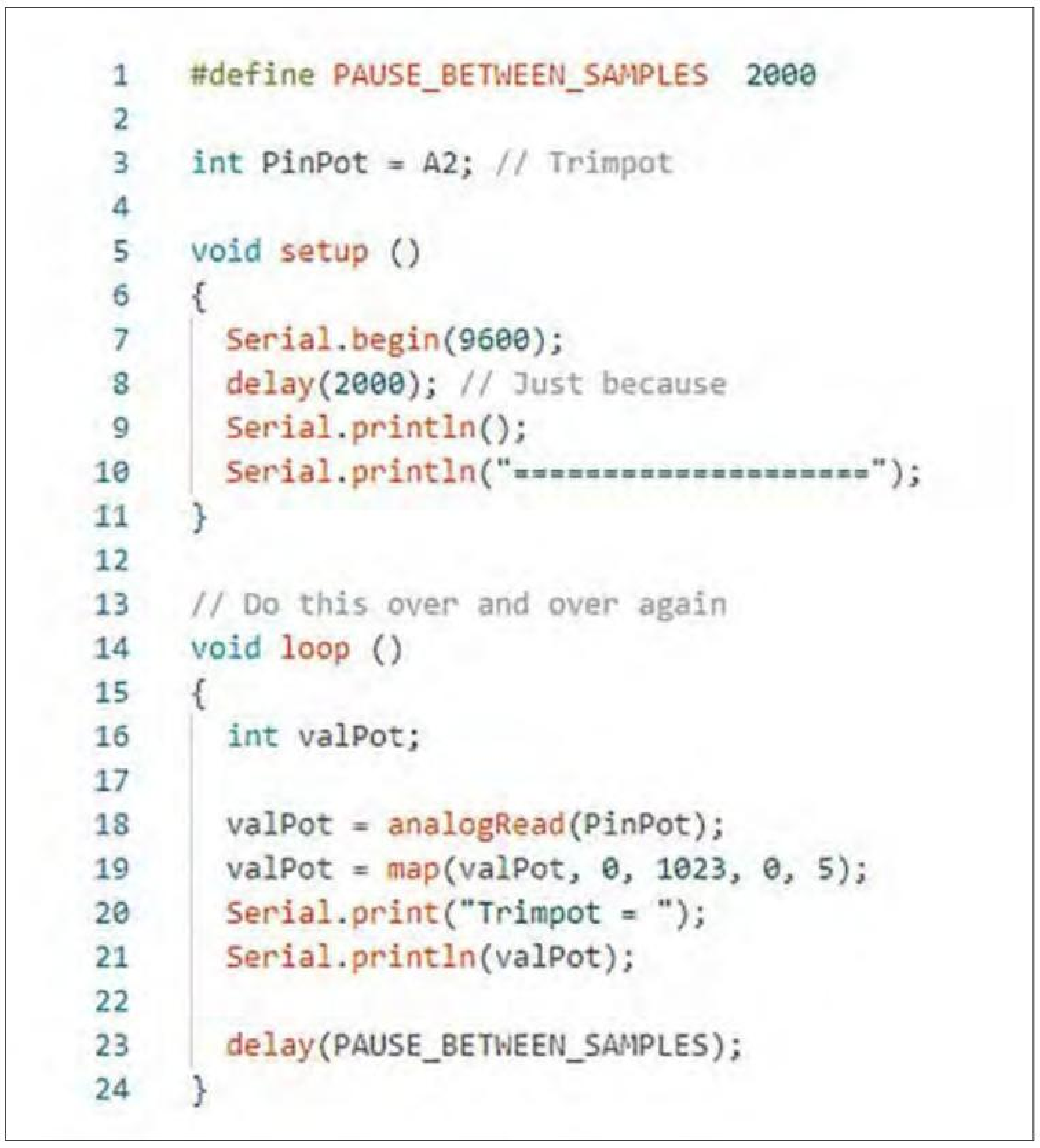

Gazins
Potentiometer
(Rotation)
Light-Dependent Resistor (LDR)
(Ambient Light)
Ultrasonic Sensor
(Distance)
Arduino Uno
Gazouts
Piezoelectric Buzzer
(Frequency)
7-Segment Display)
(Flash Rate)
(Numerical Value)
(Brightness/Intensity)

Fig.1. Gazins and Gazouts.



```
#define PAUSE_BETWEEN_SAMPLES  2000

int PinPot = A2; // Trimpot

void setup ()
{
  Serial.begin(9600);
  delay(2000); // Just because
  Serial.println();
  Serial.println("====================");
}

// Do this over and over again
void loop ()
{
  int valPot;

  valPot = analogRead(PinPot);
  valPot = map(valPot, 0, 1023, 0, 5);
  Serial.print("Trimpot = ");
  Serial.println(valPot);

  delay(PAUSE_BETWEEN_SAMPLES);
}
```

Listing 1. Where we left things last time.

Setting the scene

Just to ensure we're all tapdancing to the same skirl of the bagpipes, let's briefly refresh our memories as to where we last left off. We started by adding a potentiometer (pot) called a trimpot (trimmer pot) to our breadboard (Fig.2).

You know the drill by now. All the files mentioned in this column are available from the November 2023 page of the *PE* website (**https://bit.ly/pe-downloads**). As usual, you can download an image of our current breadboard layout showing

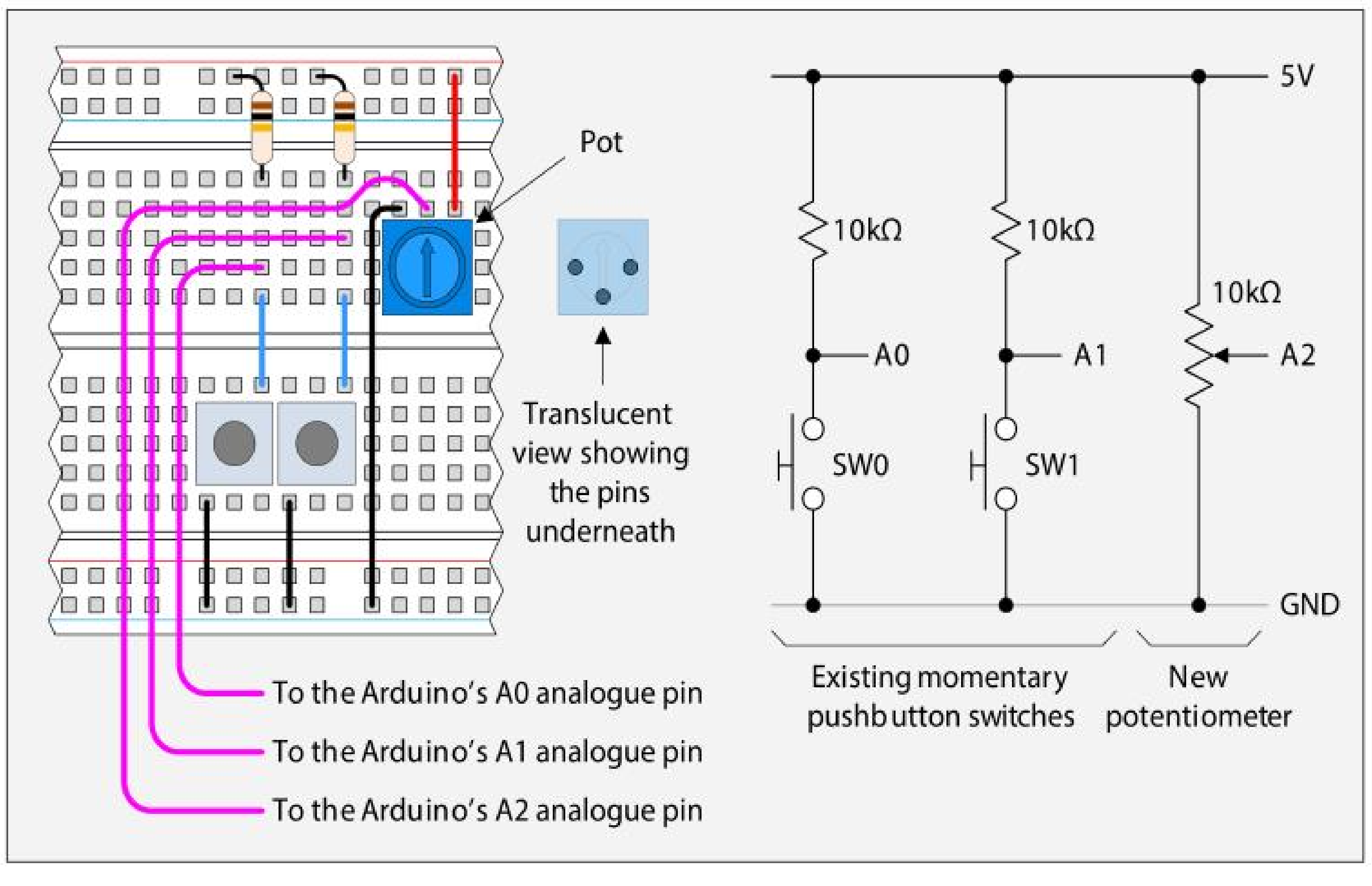
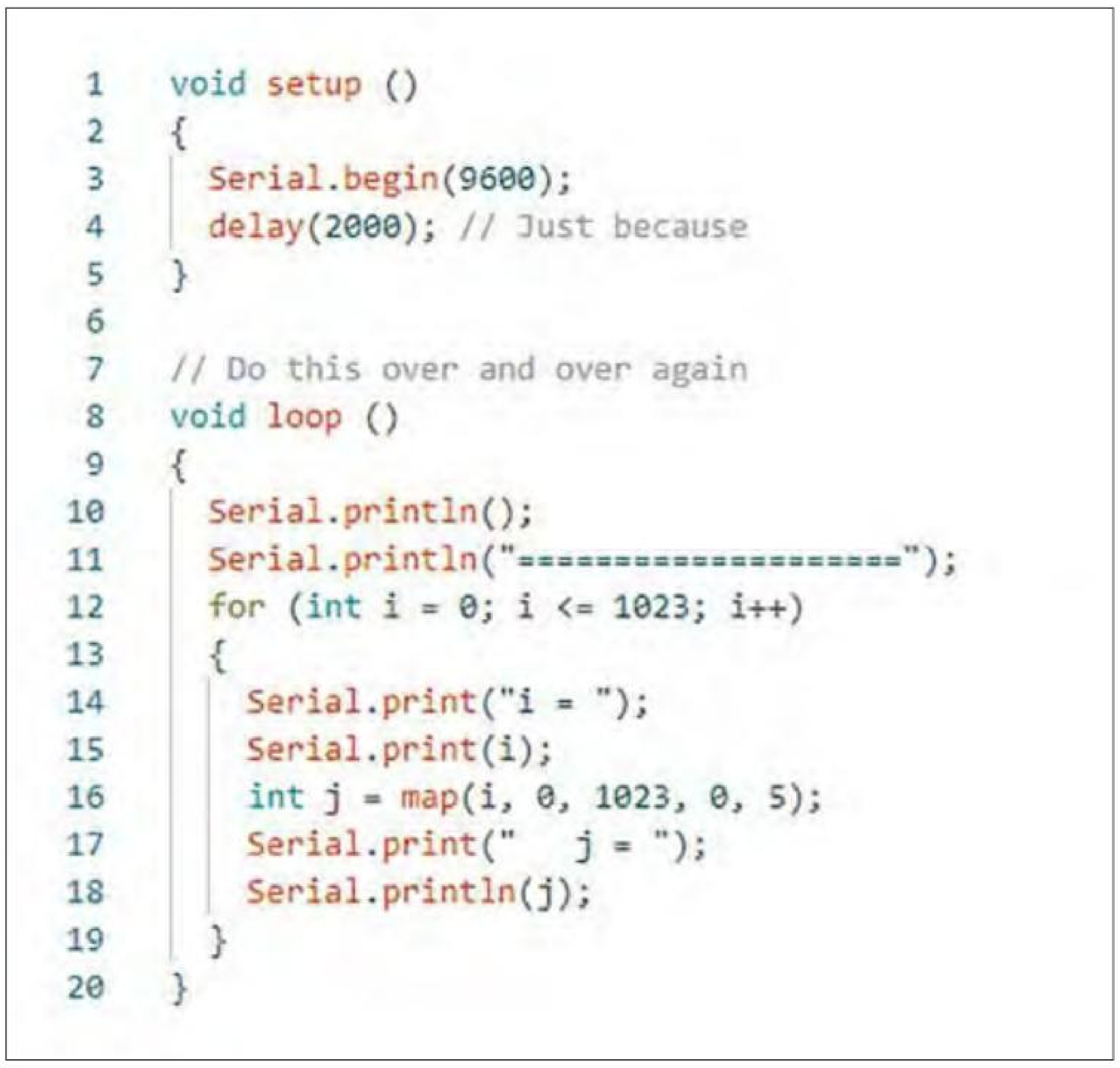

Pot
Translucent view showing the pins underneath
To the Arduino's A0 analogue pin
To the Arduino's A1 analogue pin
To the Arduino's A2 analogue pin
5V
10kΩ
10kΩ
10kΩ
A0
A1
A2
SW0
SW1
GND
Existing momentary pushbutton switches
New potentiometer

Fig.2. Adding the trimpot to the breadboard.



```
void setup ()
{
  Serial.begin(9600);
  delay(2000); // Just because
}

// Do this over and over again
void loop ()
{
  Serial.println();
  Serial.println("====================");
  for (int i = 0; i <= 1023; i++)
  {
    Serial.print("i = ");
    Serial.print(i);
    int j = map(i, 0, 1023, 0, 5);
    Serial.print("   j = ");
    Serial.println(j);
  }
}
```

Listing 2. A cheap and cheerful test program.

the switches, our trimpot, our piezoelectric buzzer, and our 7-segment display – along with various pull-up and current-limiting resistors – coupled with the connections to our Arduino Uno (file **CB-Nov23-01.pdf**).

As you may recall, we commenced by writing a program to loop around reading values from the trimpot and presenting these values in the Serial Monitor on our host computer. Since the Arduino Uno's analogue inputs are processed using an internal 10-bit analogue-to-digital converter (ADC), and since 10 bits can code $2^{10} = 1024$ patterns of 0s and 1s, the values we see from the trimpot range between 0 and 1023.

The final version of our program employed the Arduino's built-in `map()` function to map this 0 to 1023 range of values to a new 0 to 5 range, which we said we were going to regard as representing voltages between 0V and 5V rounded to the nearest volt. You can peruse and ponder this program in its entirety in Listing 1 (file **CB-Nov23-02.txt**).

On Line 3 we declare a global integer variable called `PinPot`, which we assign to the Arduino's analogue pin A2. This is the pin that's connected to the trimpot on our breadboard. One question you might be asking yourself is why we aren't calling the Arduino's built-in `pinMode()` function in our `setup()` function to specify whether we are going to use `PinPot` as an input or an output. The answer is that we are going to be using `PinPot` as an analogue input, and we need to use the `pinMode()` function only for pins we intend to employ as digital inputs and outputs.

The only really interesting thing in our `setup()` function occurs on Line 7 when we initialise the serial communications to allow the Arduino to 'talk' to our host computer and display information in the Serial Monitor (the use of the Serial Monitor was discussed in *PE*, May 2023 and October 2023).

Our `loop()` function is also easy peasy lemon squeezy. On Line 16 we declare an integer variable called `valPot` ('value from the potentiometer'). On Line 18 we assign the value returned from calling the Arduino's built-in `analogRead()` function to our `valPot` variable. On Line 19 we call the Arduino's built-in `map()` function to map one range of values (the 0 to 1023 values we read from our trimpot, in this example) into another range of values (0 to 5 in this example). Then we use Lines 20 and 21 to display our new values in the Serial Monitor.

As we tweak the position of our trimpot, the result will look something like the following:

```
===========
Trimpot = 2
Trimpot = 2
Trimpot = 3
Trimpot = 4
Trimpot = 4
        :
```

What did you expect?

To be honest, the code in Listing 1 might not behave quite the way you expect. Of course, this all depends on what you do expect. Take a moment to ponder and predict what the `map()` function will return when presented with our 0 to 1023 range of trimpot readings.

The easiest way to determine what actually happens in the real world is to whip up a quick-and-easy test program, as seen in Listing 2 (file **CB-Nov23-03.txt**).

All we are doing here is cycling an integer variable called `i` from 0 to 1023 to simulate the range of values we expect from our trimpot, mapping these values onto a range from 0 to 5, assigning these new values to an integer variable called `j`, and printing the `i` and `j` values in the Serial Monitor on our host computer. If we run this program, we discover the following:

```
i =    0 to  204   j = 0
i =  205 to  409   j = 1
i =  410 to  613   j = 2
i =  614 to  818   j = 3
i =  819 to 1022   j = 4
i = 1023           j = 5
```

Is this what you expected? Is this what we want? One clue is when I said: '[…] a new 0 to 5 range, which we can regard as representing voltages between 0V and 5V *rounded* to the nearest volt.' To be honest, I was a little naughty here because I didn't define what we meant by rounding in this context, and there are many different rounding algorithms to choose from. You were probably expecting a 'round-half-even' implementation, but what we see here is a 'round-toward-zero' approach (visit the article I wrote at: **https://bit.ly/3PlIF3f** to learn more about different rounding algorithms).

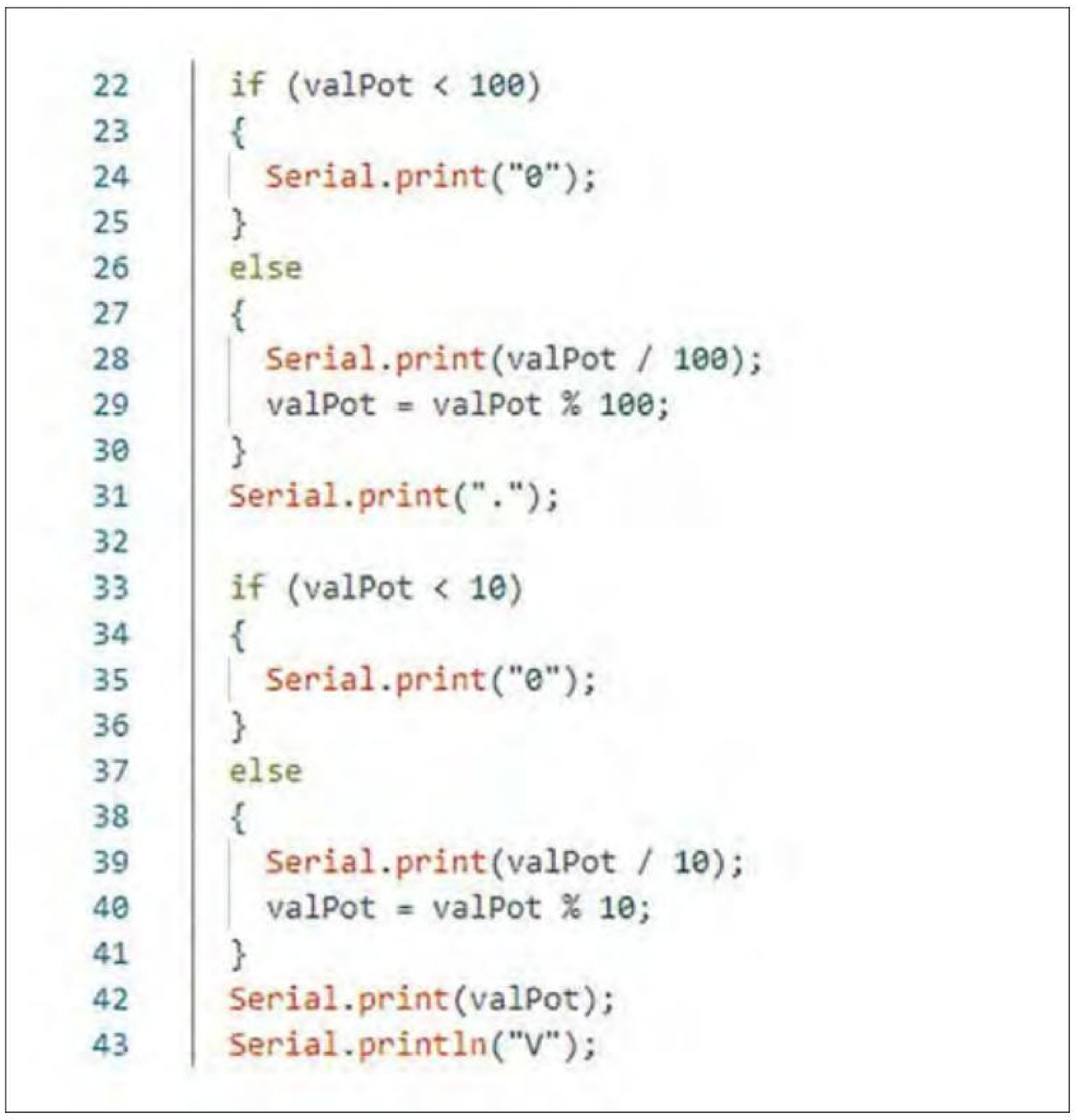
Homework assignment #1

Our first homework assignment was to modify our latest program such that it displays voltage values with two significant fractional digits, such as 0.00, 1.41, 3.30, 4.99 and 5.00. Why don't you take a moment to think how you would do this, and then compare your solution to mine as follows.

First, I modified the call to the `map()` function. I left the input range as 0 to 1023 to reflect the values from our trimpot, but I changed the output range to 0 to 500. Second, as opposed to simply outputting the value of `valPot` (Line 21 in Listing 1), I implemented a primitive formatting algorithm, as seen in Listing 3 (the entire program is available in file **CB-Nov23-04.txt**).

Remember that we want to see our voltage values displayed in the range 0.00V to 5.00V. This is what our algorithm does. If the value read and mapped from our potentiometer is less than 100 (1V), as tested on line 22, then we output a '0' character (Line 24). Otherwise, we output the value divided by 100 (Line 2), which equates to the most significant digit (the 'hundreds' digit) in our 3-digit value (remember that the division operator '/' truncates or discards any remainder), after which we use the modulo operator (`%` on line 29) to get rid of the most significant digit, leaving the remainder, which will have a value of 0 to 99.

After printing a full stop '.' (Line 31), we perform a similar exercise to output the 'tens' digit (Lines 33 to 41). Finally, we print the 'ones' digit (Line 42), after which we add a 'V' character to signify that we are considering these values to represent voltages.



```
if (valPot < 100)
{
  Serial.print("0");
}
else
{
  Serial.print(valPot / 100);
  valPot = valPot % 100;
}
Serial.print(".");

if (valPot < 10)
{
  Serial.print("0");
}
else
{
  Serial.print(valPot / 10);
  valPot = valPot % 10;
}
Serial.print(valPot);
Serial.println("V");
```

Listing 3. A primitive formatting algorithm.

Does this work? Like a charm! Try loading and running this program on your own Arduino Uno, vary the position of the trimpot on your breadboard, and observe the results being displayed in your Serial Monitor.

Alternatively, if you are just reading along, but you haven't yet implemented this circuit on your breadboard, then you can load a modified version of the program shown in Listing 2, where this new version implements our primitive formatting algorithm (file **CB-Nov23-05.txt**). As you'll see, the results are just the way we want to see them:

```
i =    0   j = 0.00V
i =    1   j = 0.00V
i =    2   j = 0.00V
i =    3   j = 0.01V
i =    4   j = 0.01V
i =    5   j = 0.02V
i =    6   j = 0.02V
      :
i = 1017   j = 4.97V
i = 1018   j = 4.97V
i = 1019   j = 4.98V
i = 1020   j = 4.98V
i = 1021   j = 4.99V
i = 1022   j = 4.99V
i = 1023   j = 5.00V
```

When you think about it, we've essentially created a simple voltmeter, which should set all sorts of random thoughts rattling around our noggins.

Homework assignment #2

One of the things that bugs me about our current program is that we are constantly writing new values to the Serial Monitor. Most of the time this is a waste of time because we only occasionally change the position of our potentiometer.

This explains our second homework assignment, which was to modify the program such that it only displays a new value in the Serial Monitor if the voltage changes by 0.01V or more.

Let's work with the latest and greatest version of our program (file **CB-Nov23-04.txt**). We are going to remove the `PAUSE_BETWEEN_SAMPLES` definition on Line 1 along with the call to the `delay()` function that employed this definition at the end of our `loop()` function.

Next, we're going to declare a global integer variable called `OldPot` and assign it a value of –1 (this value guarantees that the first time we compare it to the value we read from our trimpot, we know for sure they won't be the same.

Finally, we're going to modify our `loop()` function as shown in Listing 4 (file **CB-Nov23-06.txt**). As we see, we still read the value from the trimpot (Line 18) and map it to our desired range of values (Line 19). The only thing that changes is that we now perform a test (Line 21) to see if the new value we just read (stored in our local `valPot` variable) differs from the previous value we read (stored in our global `OldPot` variable). If there is a difference, we update our `OldPot` variable to reflect this new value (Line 23), after which we employ our existing formatting algorithm to output the new value.

WTW?

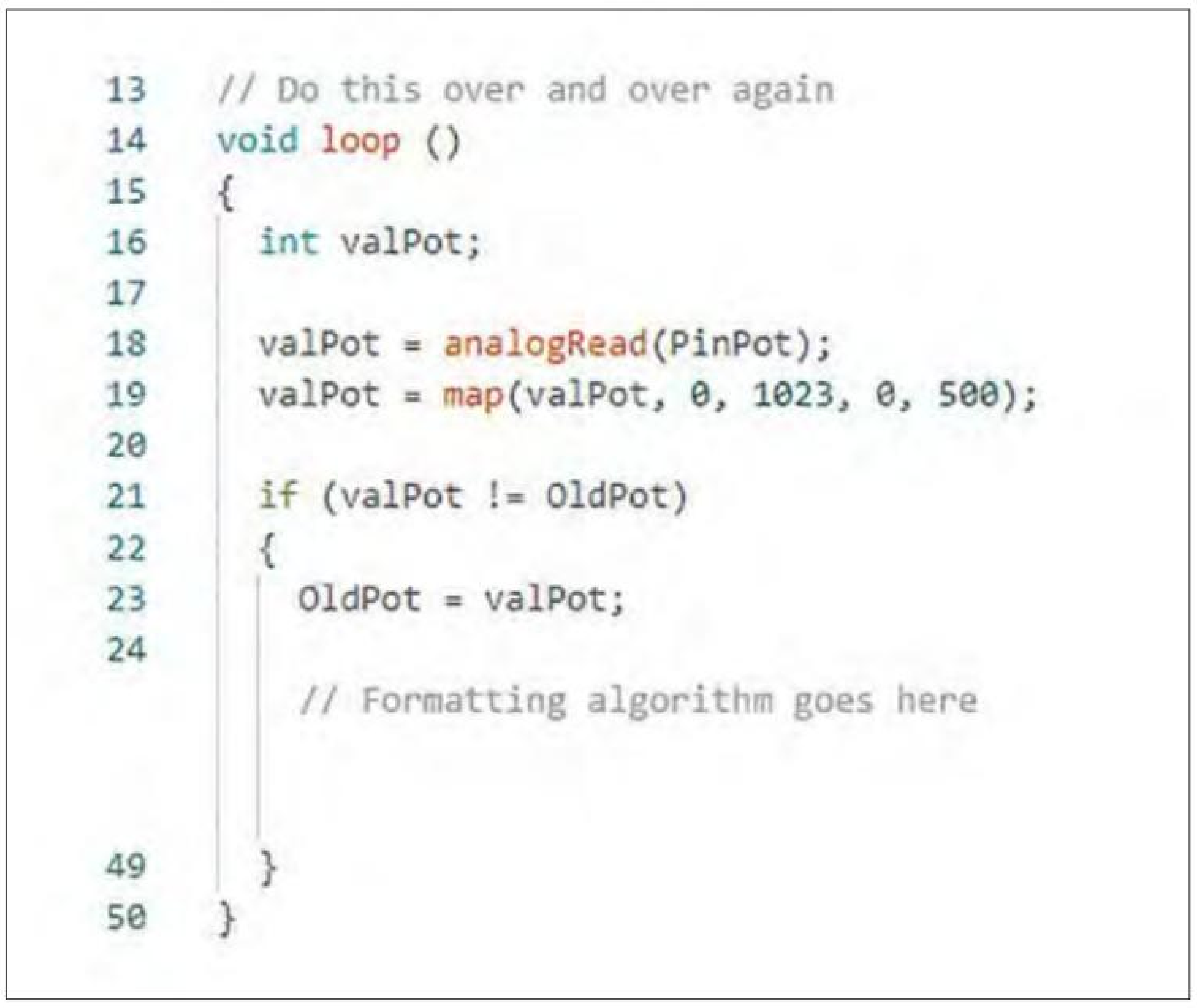
'What the What (WTW)?' is one of my new favorite expressions. The whole purpose of the latest incarnation of our program is to prevent numerous lines being written to our Serial Monitor. I don't know what you are seeing, but it's certainly not working in my case. I started off with my trimpot roughly in its center position. The output in my serial monitor looks like the following:

```
================
Trimpot = 2.50V
Trimpot = 2.49V
Trimpot = 2.50V
Trimpot = 2.49V
Trimpot = 2.50V
Trimpot = 2.49V
```

'What can be causing this travesty?' I hear you cry. Well, here's the deal. When we read from a digital input, the value is (hopefully) a hard 0 or a hard 1. By comparison, in the case of an analogue input, the signal being fed into the input is subject to various sources of noise. As a result, every time we read the analogue input, it's value can vary a little one way or the other.

There are various possible solutions to this issue. In hardware, for example, we might try adding a capacitor to the input. However, my box of capacitors is all the way across the room, and I don't feel like getting up at this moment in time. The simplest software solution is to modify the test in Line 21 of Listing 4. As opposed to our current test…

```
if (valPot != OldPot)
```



```
13  // Do this over and over again
14  void loop ()
15  {
16    int valPot;
17
18    valPot = analogRead(PinPot);
19    valPot = map(valPot, 0, 1023, 0, 500);
20
21    if (valPot != OldPot)
22    {
23      OldPot = valPot;
24
        // Formatting algorithm goes here

49    }
50  }
```

Listing 4. Only output if something changes.

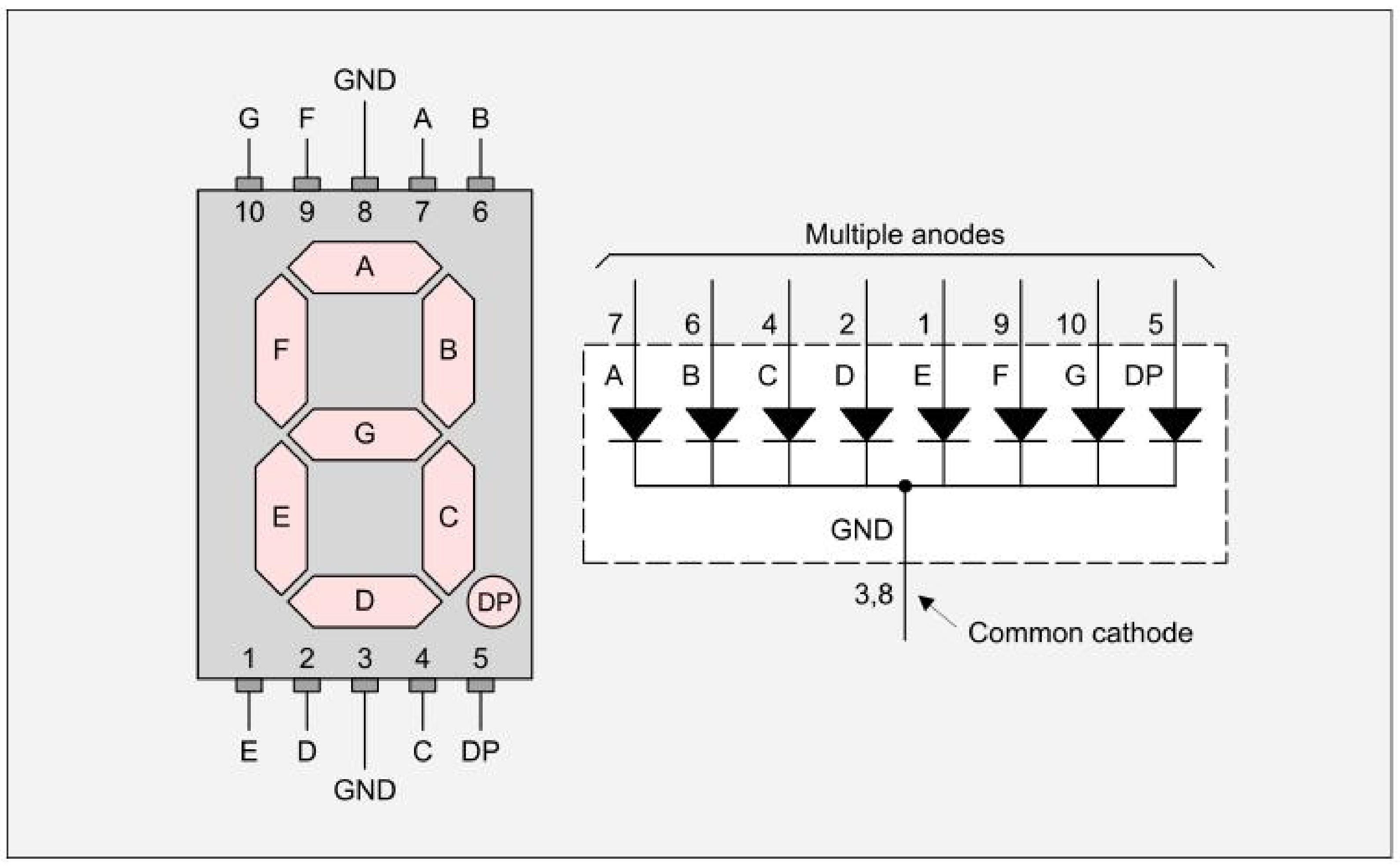


Fig.3. Our common-cathode 7-segment display.

…which we can read as: 'If the new value on the pot is not equal to the old value on the pot,' we can change this to the following…

```
if ( abs(valPot - OldPot) > 1 )
```

…which we can read as: 'if the absolute value of the difference between the new value in the pot and the old value on the pot is greater than 1.'

How does this work? Well, if we subtract our old pot value from our new pot value, we could end up with a positive number, a negative number, or 0. The Arduino's built-in `abs()` function returns the absolute value of a number; that is, the number without its sign. What this means is that `abs(+2)` and `abs(-2)` will both return 2, for example.

As an aside, when we think about it, in this case it doesn't matter whether we subtract the old value on the pot from the new value, or vice versa, because the result returned from the `abs()` function will be the same.

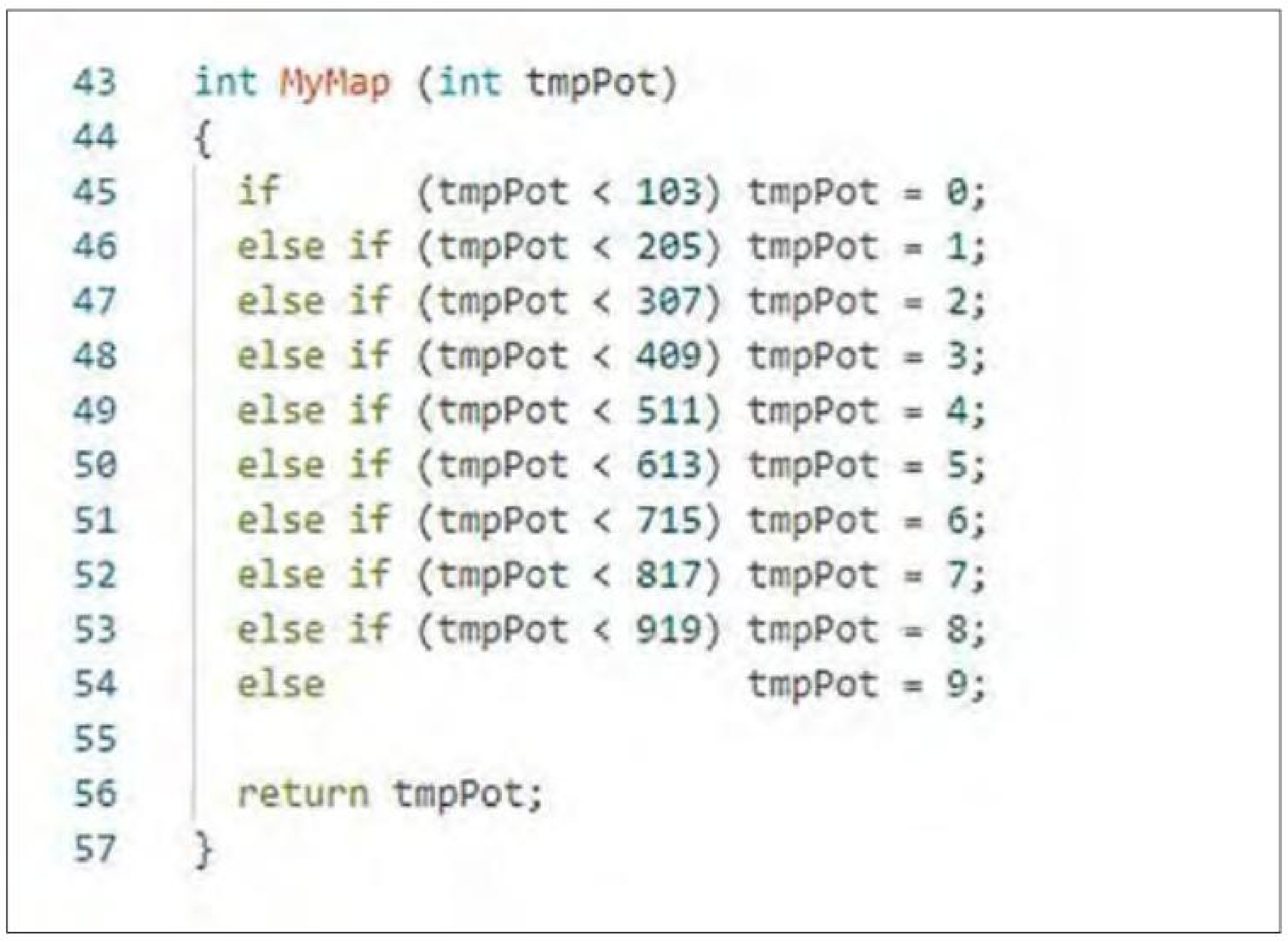
When I run this 'tweaked' version of the program (file **CB-Nov23-07.txt**), I see the following, which stays the same until I change the position of my pot.

```
================
Trimpot = 2.50V
```

I feel a small 'Tra-la!' is in order.

Taking a break

I don't know about you, but I don't like homework, so let's take a little break. What we are going to do is map the 0 to 1023 input values read from our trimpot onto a range of 0 to 9 and – in addition to writing these values to the Serial Monitor – use these values to control the speed of a flashing segment on our 7-segment display.



```
int MyMap (int tmpPot)
{
  if      (tmpPot < 103) tmpPot = 0;
  else if (tmpPot < 205) tmpPot = 1;
  else if (tmpPot < 307) tmpPot = 2;
  else if (tmpPot < 409) tmpPot = 3;
  else if (tmpPot < 511) tmpPot = 4;
  else if (tmpPot < 613) tmpPot = 5;
  else if (tmpPot < 715) tmpPot = 6;
  else if (tmpPot < 817) tmpPot = 7;
  else if (tmpPot < 919) tmpPot = 8;
  else                   tmpPot = 9;

  return tmpPot;
}
```

Listing 5. Our own mapping function.

Just for giggles and grins, we are going to flash the 'D' segment at the bottom of the display (Fig.3). This is pin 2 on the display, and it's connected to digital pin 6 on our Arduino Uno (see the circuit diagram in file **CB-Nov23-01.pdf**).

Let's say that a mapped value of 0 from our trimpot causes the slowest flash (one second on and one second off), and that we progress in 1/10th second (0.1s, 100ms (milliseconds)) increments to a mapped value of 9 from our trimpot, which causes the fastest flash (1/10 second on and 1/10 second off).

What we're going to do is use our original program from Listing 1 as a starting point, along with a few of the changes we've made along the way, like only outputting new values to the serial monitor. Also, we're going to flash segment D on the 7-segment display.

Before we do this, however, we need to make a decision regarding our use of the Arduino's built-in `map()` function. Based on our earlier discussions, we now know that this won't ideally serve our purposes with respect to what we are trying to do here. What we really want to see is something like the following:

```
--Trimpot--  Map
  0 to  102   0
103 to  204   1
205 to  306   2
307 to  408   3
409 to  510   4
511 to  612   5
613 to  714   6
715 to  816   7
817 to  918   8
919 to 1023   9
```

One way to achieve this is to create our own mapping function called `MyMap()` as illustrated in Listing 5.

Now let's look at the main body of our new program to vary the speed of flashing segment D, as shown in Listing 6 (file **CB-Nov23-08.txt**).

There's nothing here that we've not seen before in one form or another. On Line 1 we define the value associated with our slowest flash, `BASE`, which we will use to flash our segment 1 second on and 1 second off. On Line 2 we declare `DELTA`, the incremental difference between flash durations as being 100ms.

In addition to declaring the pin connected to our pot on Line 4, we also declare the pin connected to segment D of the 7-segment display on Line 5. Observe that, in this case, since this is a digital pin that we wish to use as an output, we call the `pinMode()` function on Line 13 and then we drive this output to 0 (thereby turning the segment off) on Line 14.

Our `loop()` function starts off the way it did before, except it now calls our new `MyMap()` function on Line 27. We use Lines 29 to 34 to write the mapped value from our trimpot to the Serial Monitor. On Line 36, we declare an integer called `flash` to which we assign the result from a simple calculation that determines the delay we wish to use to flash our segment based on the mapped value from our trimpot. Finally, on Lines 37 to 40 we turn the segment on, pause, turn the segment off again, pause once more, and 'Bob's your uncle' (or aunt, depending on your family dynamic).

Load this program into your Arduino and observe how the rate of flash varies with the position of the trimpot. I know this is all simple stuff, but I still feel a glow of satisfaction when I see things working as planned (especially when a flashing LED is involved).

Blinded by the light

Do you have an LED-based alarm clock in your bedroom? If so, then assuming it's not the cheapest version you could lay your hands on, when you turn the room lights off at night,

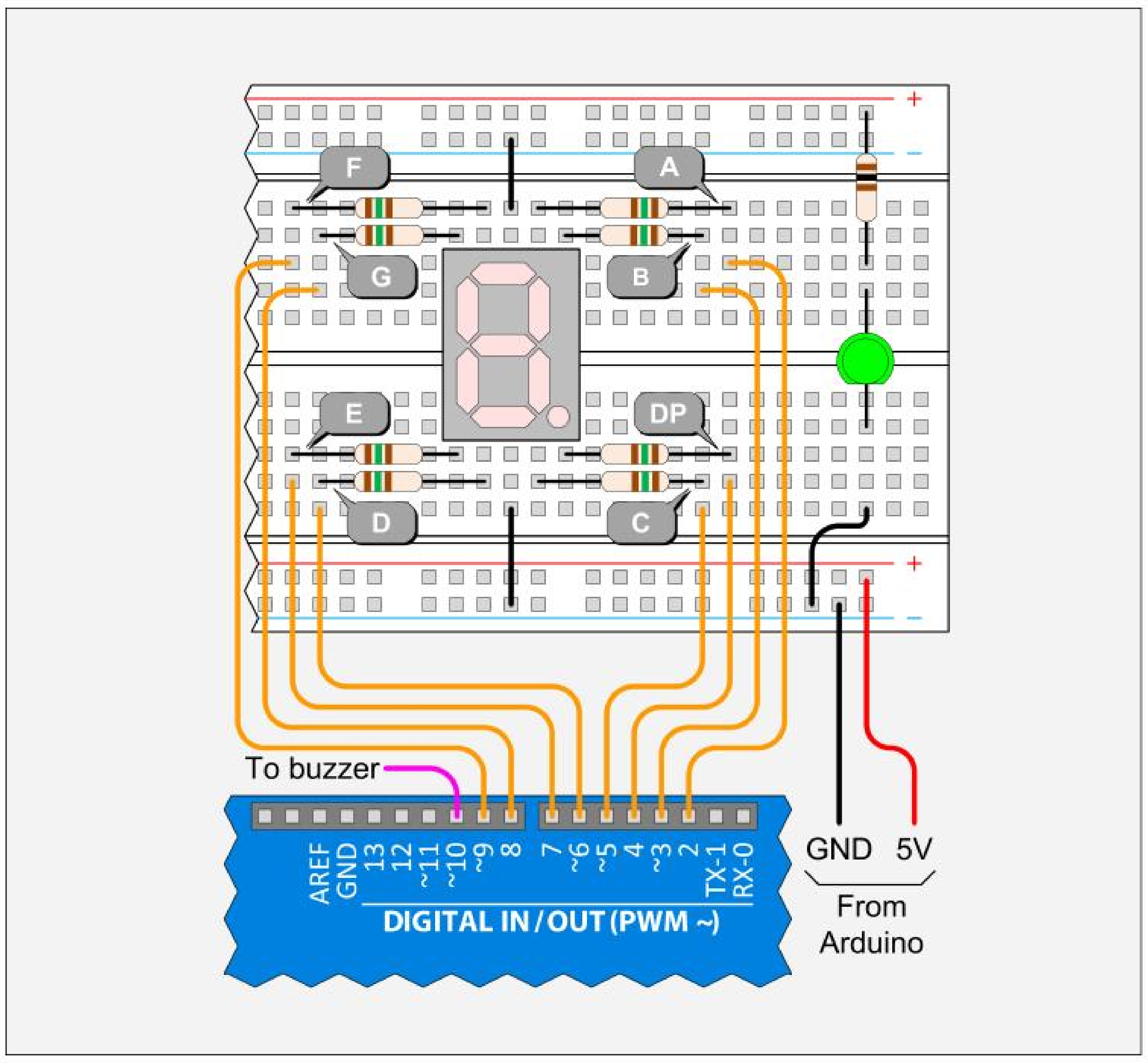


Fig.4. The Arduino Uno's PWM pins.

the brightness of the clock's display should automatically reduce accordingly.

One way to detect the level of ambient light is to use a component called a light-dependent resistor (LDR). This is one of the sensors with which we will be experimenting in next month's column. Also, just to give you a sneak peak of what's heading our way in future columns, we are going to gather everything we've learned thus far (along with a bunch more stuff) to develop a suite of clocks using one, two, and four 7-segment displays. In addition to telling the time, we will be using our LDR to dim the displays at night, while our piezoelectric buzzer will provide chime and audible alarm functions. But we digress…

Let's stick with segment D on our 7-segment display for the moment. How can we control the brightness of this LED? Let's take a step back and think about this for a moment. In our previous experiment we flashed segment D. When the segment is off, its brightness is 0%. When the segment is on, its brightness is 100%. Since we are flashing this segment fairly slowly in the scheme of things – using identical on and off times ranging from 1/10th of a second to a second – our eyes perceive these states as being fully on or fully off. Similarly, if we were using a light meter to measure the amount of light being emitted from the LED, we would see its reading oscillating between 0% and 100%. But suppose we were to average the light meter's readings over some *longer* period, like an hour, for example. In this case, the average intensity would be only 50%.

Hmmm. Suppose we repeatedly turn the LED on for 1ms and off for 1ms. In this case, the pulses will be far too fast for our eyes to detect individually. Instead, we will perceive the LED as running at 50% brightness. How about if we repeatedly turn the LED on for 1ms and off for 3ms? Since the LED is now on for only a quarter of the time, our eyes will perceive it as running at 25% brightness. Similarly, if we repeatedly turn the LED on for 3ms and off for 1ms, our eyes will perceive it as running at 75% brightness.

One big problem with this solution is that the Ardunio would spend most of its time turning LEDs on and off, leaving little processing power to perform other activities. Fortunately, there is an alternative option. Arduinos include special hardware implementations of pulse-width modulation (PWM) functions associated with some of their digital pins. In the case of the Arduino Uno, there are six such pins (3, 5, 6, 9, 10, 11), indicated by '~' characters on the board (Fig.4).

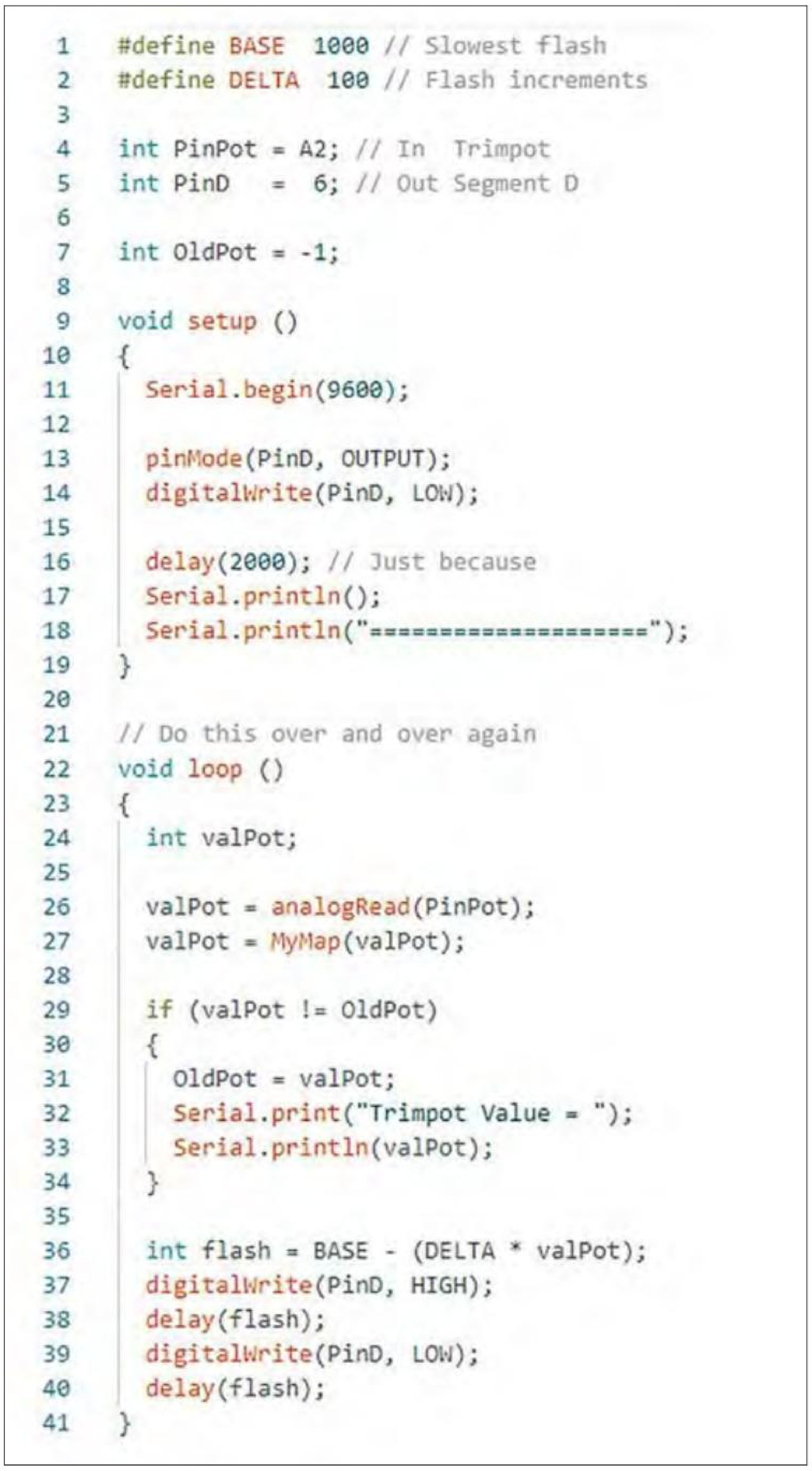
Happily, the digital pin we are using to drive segment D on the 7-segment display is pin 6, which is one of the pins that's equipped with a PWM function (it's almost as if we had a plan).

The Arduino doesn't have true analogue outputs, but the digital PWMs provide a pseudo-analogue capability (we introduced this concept previously in *PE*, March 2023). We access the PWMs using calls to the Arduino's built-in `analogWrite()` function. This function accepts two arguments – the pin we wish to control and a value between 0 and 255, which controls the mark:space (on:off) ratio on the output.

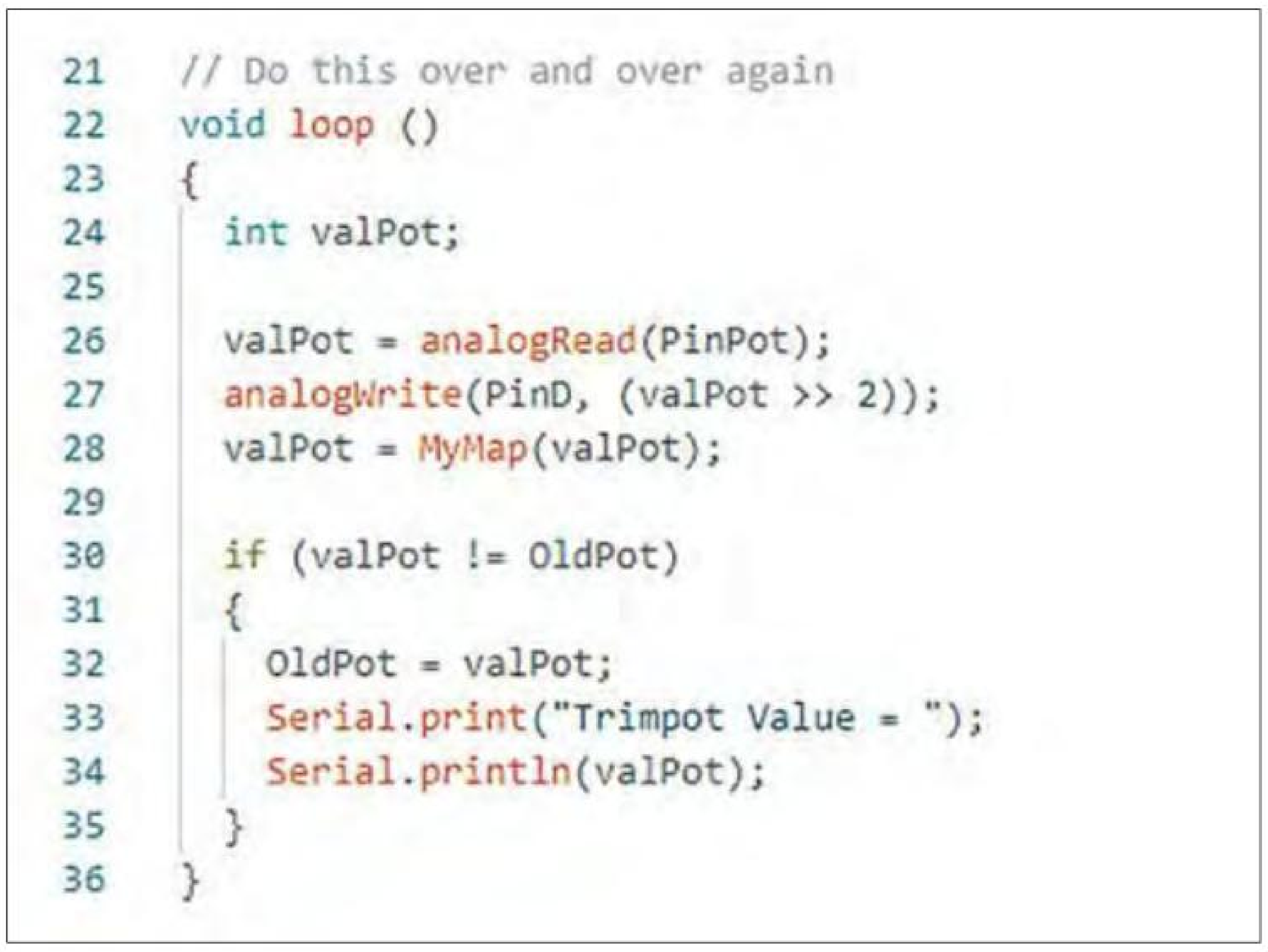
The easiest way to wrap one's brain around this is to look at some code and see it in action. With respect to the code, we can modify our `loop()` function as illustrated in Listing 7 (file **CB-Nov23-09.txt**).

The clever part here occurs on Line 27. We know that the value we read from our trimpot and store in our `valPot` variable will be in the range 0 to 1023. We also know that the `analogWrite()` function requires a value in the range 0 to 255. In a crunchy nutshell, we can obtain the value we wish to feed into the `analogWrite()` function by dividing the value read from the trimpot by 4, and this is just what we do on Line 27 using the shift right operator >>.

We introduced this operator in an earlier column (*PE*, April 2023). In that column, we explained how shifting a binary value one bit to the right is equivalent to a divide by 2, which


```
#define BASE  1000 // Slowest flash
#define DELTA  100 // Flash increments

int PinPot = A2; // In  Trimpot
int PinD   =  6; // Out Segment D

int OldPot = -1;

void setup ()
{
  Serial.begin(9600);

  pinMode(PinD, OUTPUT);
  digitalWrite(PinD, LOW);

  delay(2000); // Just because
  Serial.println();
  Serial.println("===================");
}

// Do this over and over again
void loop ()
{
  int valPot;

  valPot = analogRead(PinPot);
  valPot = MyMap(valPot);

  if (valPot != OldPot)
  {
    OldPot = valPot;
    Serial.print("Trimpot Value = ");
    Serial.println(valPot);
  }

  int flash = BASE - (DELTA * valPot);
  digitalWrite(PinD, HIGH);
  delay(flash);
  digitalWrite(PinD, LOW);
  delay(flash);
}
```

Listing 6. Varying speed of flashing segment.



```
// Do this over and over again
void loop ()
{
  int valPot;

  valPot = analogRead(PinPot);
  analogWrite(PinD, (valPot >> 2));
  valPot = MyMap(valPot);

  if (valPot != OldPot)
  {
    OldPot = valPot;
    Serial.print("Trimpot Value = ");
    Serial.println(valPot);
  }
}
```

Listing 7. Varying brightness/intensity.

means shifting a binary value two bits to the right is equivalent to a divide by 4.

Load this new program into your Arduino and observe how turning your trimpot now varies the brightness of segment D on the 7-segment display.

No homework, but…

I'm not going to set any homework this month, not least that we still have two items remaining from last month. However, I would like you to start thinking about how we might vary the brightness of multiple segments on the display. Remember that we use different segment combinations to represent the digits 0 through 9. The number 8 requires us to light all seven of our segments, but we have only six PWMs. What are we going to do? All will be revealed in our next column. Until then, have a good one!

Components from Part 1

LEDs (assorted colours)	https://amzn.to/3E7VAQE
Resistors (assorted values)	https://amzn.to/3O4RvBt
Solderless breadboard	https://amzn.to/3O2L3e8
Multicore jumper wires (male-male)	https://amzn.to/3O4hnxk

Components from Part 2

7-segment display(s)	https://amzn.to/3Afm8yu

Components from Part 5

Momentary pushbutton switches	https://amzn.to/3Tk7Q87

Components from Part 6

Passive piezoelectric buzzer	https://amzn.to/3KmxjcX

Components for Part 9

SW-18010P vibration switch	https://bit.ly/46SfDA4

Components for Part 10

Breadboard mounting trimpots	https://bit.ly/3QAuz04

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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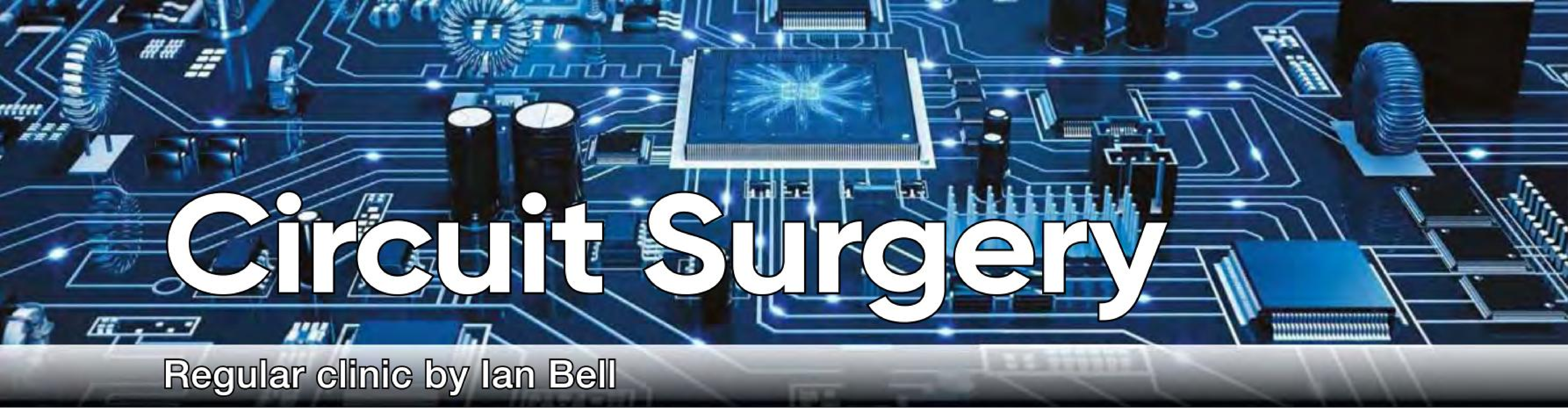


Circuit Surgery

Regular clinic by Ian Bell

Gyrators Part 3 – Parametric Equaliser Circuits

Two months ago, we looked at gyrators and specifically how a gyrator built from a single op amp can behave like an inductor, by ‘impedance converting’ a capacitor to an inductor (see Fig.1). A key use of this circuit is in filters, where the gyrator provides advantages of size, weight, cost and potentially performance over wound inductors. Last month, we discussed graphic equaliser circuits using a combination of a cut/boost amplifier and a set of *RLC* filters in which the inductors are implemented using gyrators. Equalisers provide a means of adjusting the volume of an audio signal within a set of different frequency bands, and are widely used in sound processing.

Cut/boost recap

We discussed the operation of the cut/boost circuit (Fig.2) in detail last month. To recap very briefly, the potentiometer (R_P) can be adjusted from a maximum gain (boost) with the wiper at one end through unity gain (0 dB) with the wiper at the mid-point to maximum attenuation at the other end. The maximum boost gain is given by:

$$A_{Boost} = 1 + \frac{R_{IF}}{R_G}$$

where R_{IF} is the input and feedback resistor value (they must be the same) and R_G is the grounded resistor value. The maximum attenuation in cut mode is the reciprocal of this ($A_{Cut} = 1/A_{Boost}$). This means in decibels A_{Cut} dB = $-A_{Boost}$ dB, so the circuit has symmetrical maximum cut and boost.

If we replace R_G with a frequency-dependent circuit which has a minimum resistance at a particular frequency then the boost gain, or cut attenuation, will peak at that frequency (depending on the potentiometer position). When the potentiometer is centred the gain will be unity at all frequencies. An *RLC* series circuit provides the requisite frequency dependence. An advantage of the circuit in Fig.2 is that multiple R_P/R_G circuits can be wired in parallel, without too much interaction. Using multiple *RLC* series circuits, with each tuned to a different frequency, provides the basis of equaliser circuits (see Fig.3) where the inductors can be implemented using gyrators (note the inductors are grounded).

At the resonant frequency of an *RLC* series circuit the combined impedance of an (ideal) series inductor and capacitor is zero, so the impedance of the *RLC* circuit is equal to *R*. Thus, the peak gain and attenuation with R_G in the cut/boot circuit (Fig.2) replaced with an *RLC* circuit (as in Fig.3) is found using $R_G = R$ in the above gain equations. As discussed previously, the effective series resistance of the gyrator ‘inductor’ is equal to R_2 in Fig.1, so this can be used to set the peak gain of the filter.

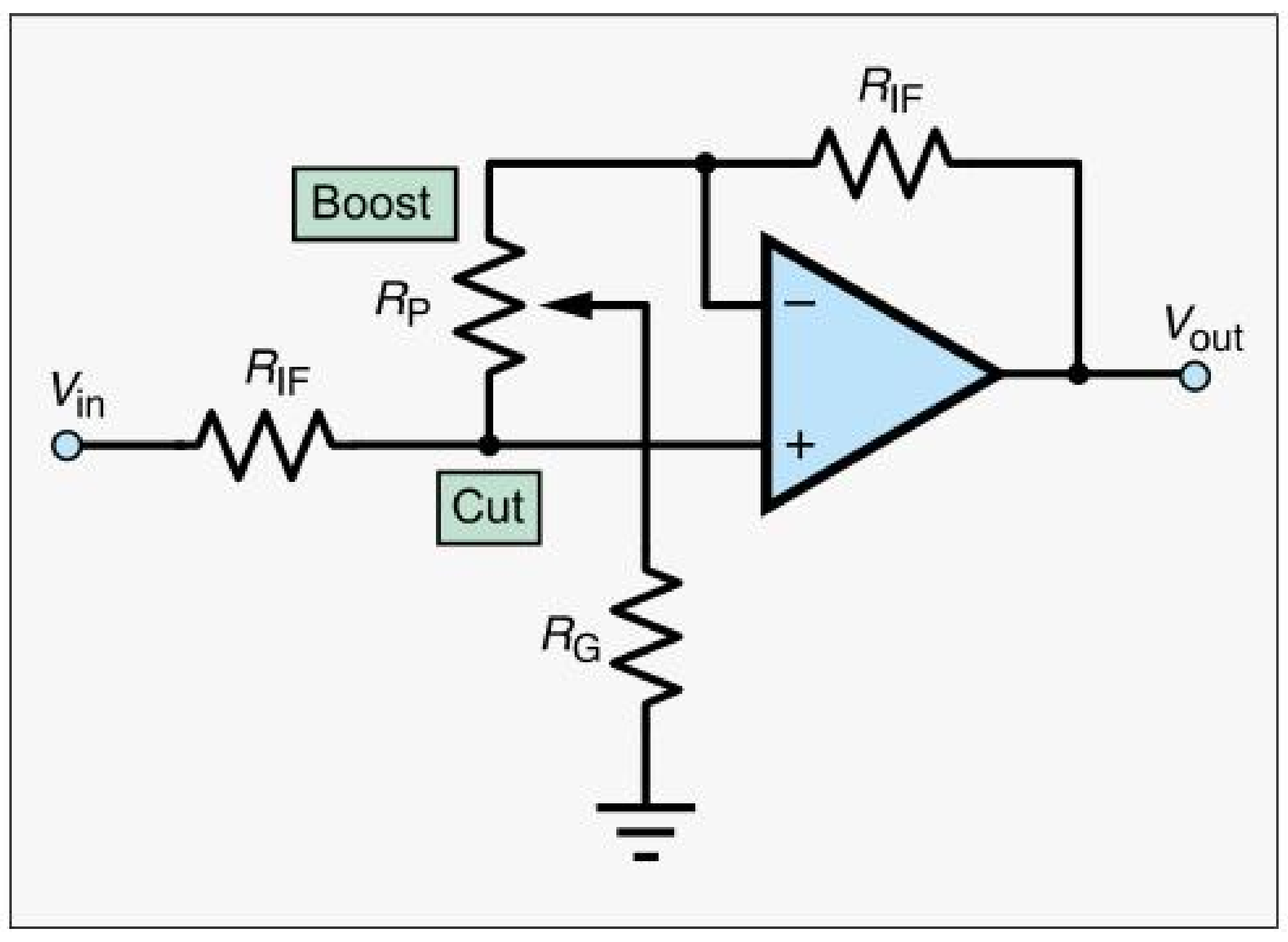


Fig.2. Cut/boost circuit.

Parametric equalisers

Last month, we concentrated on graphic equalisers, where all the channels have a fixed frequency and the only value the user can change is the level of cut/boost for each channel. Parametric equalisers provide more control over each band than graphic equalisers, with adjustable frequency and possibly bandwidth (often described as variable *Q* – see discussion on *Q* later). They may also be switchable between peaked (bandpass/bandstop) and highpass/lowpass response (shelving response). Parametric equalisers generally have far fewer channels than graphic equalisers (typically two to four, rather than up to thirty). This is similar to basic tone controls, but with much more flexibility in setting the frequency response. Parametric equalisers are found in applications such as audio

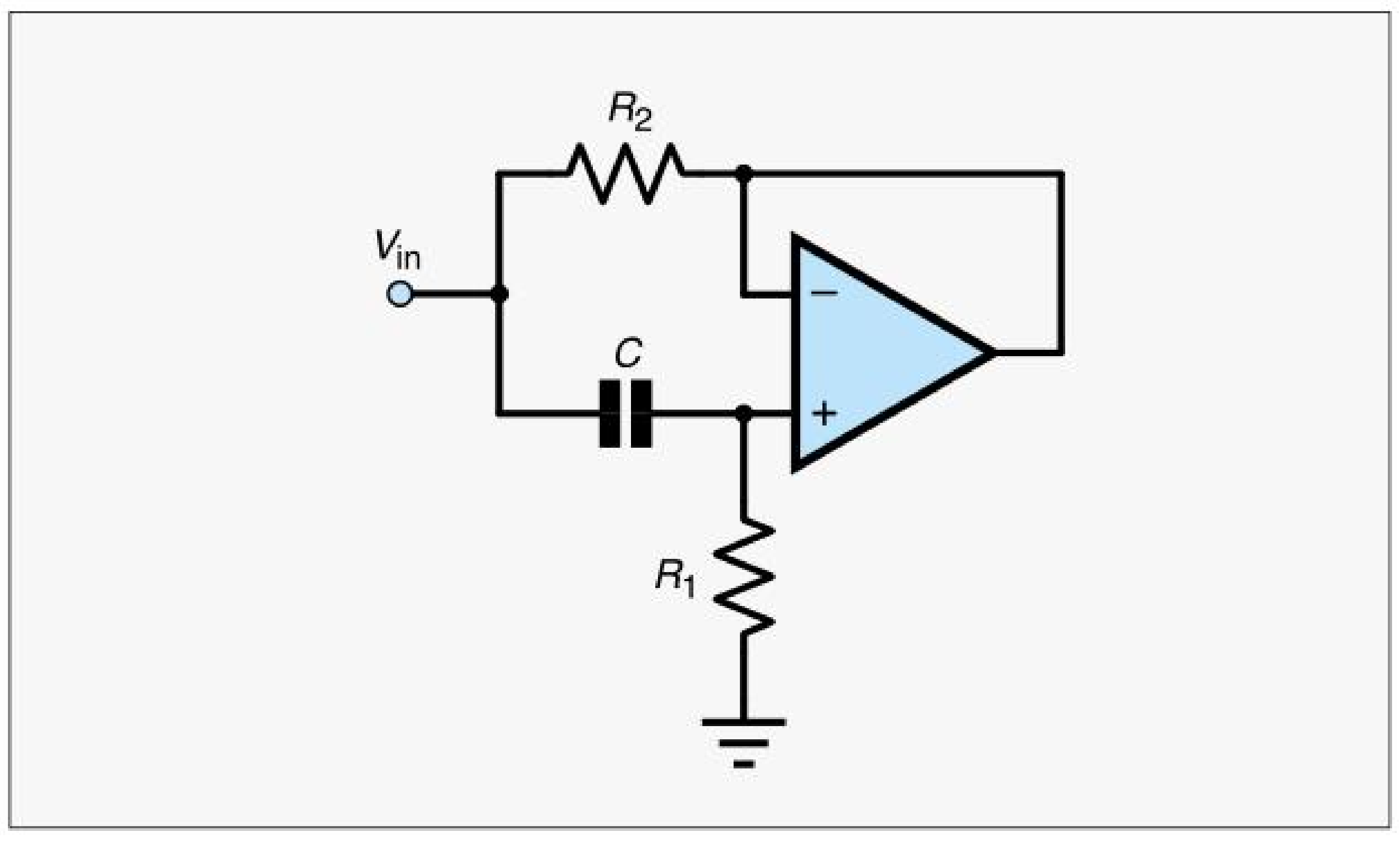


Fig.1. Gyrator – input to ground behaves like an inductor with series resistance.

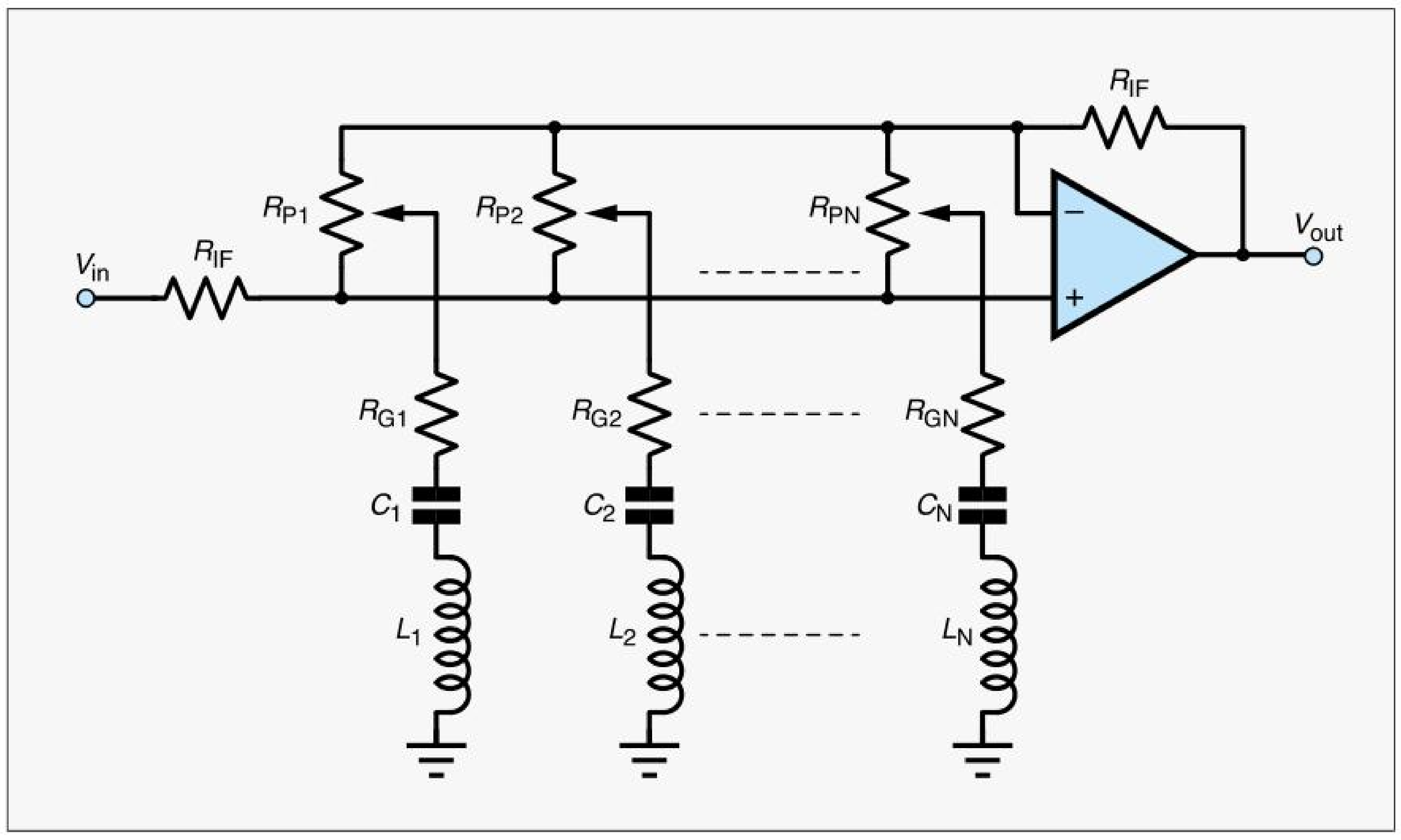


Fig.3. Graphic equaliser using cut/boost circuit with multiple gain control filters.

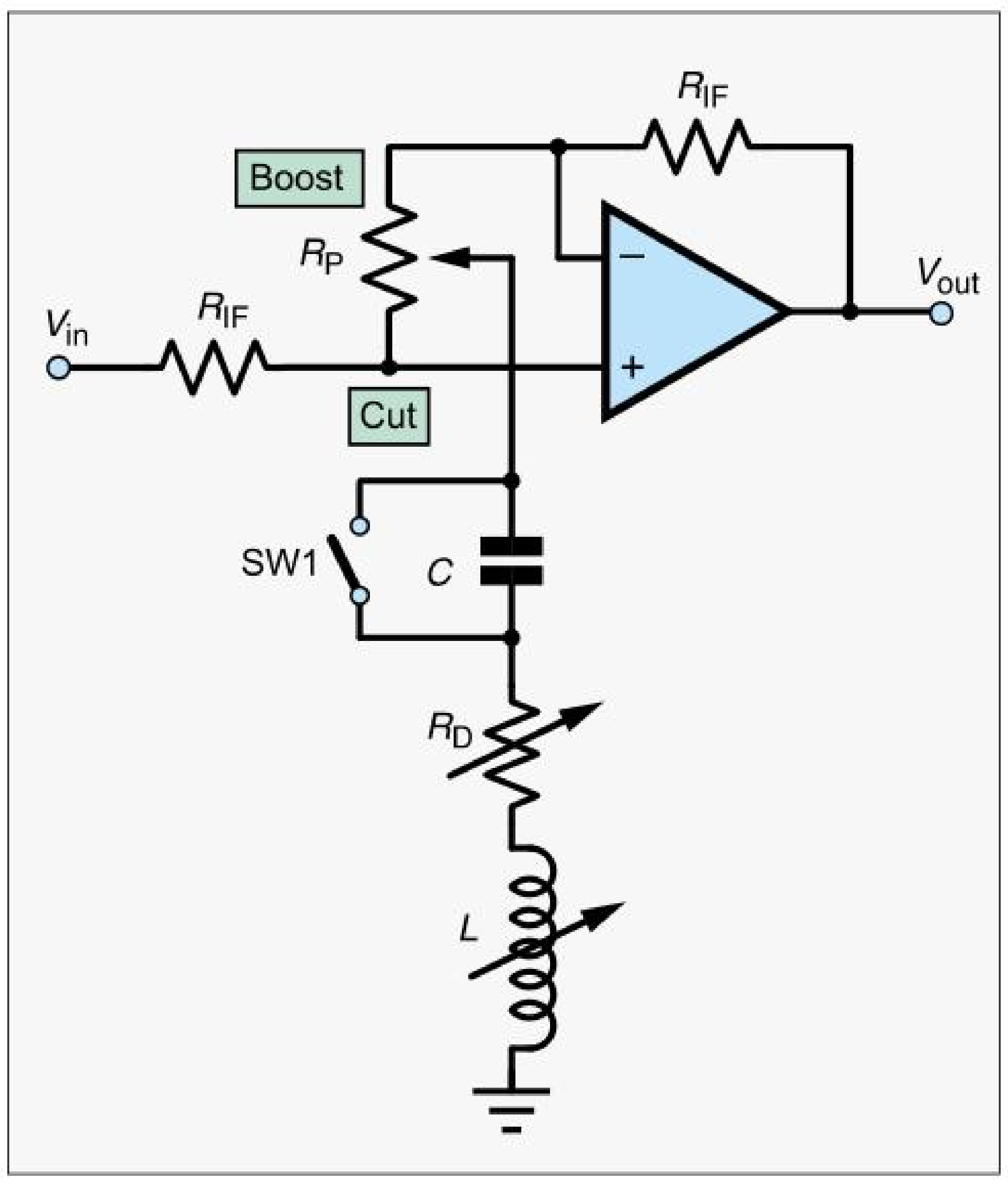


Fig.4. Cut/boost filter with parametric controls.

processing systems, modular synthesisers and effects units.

The combined gyrator and cut/boost can provide more control over its behaviour than is required for a graphic equaliser. This concept is illustrated in Fig.4 where, in addition to the cut/boost control (R_P) the inductance (L) and series resistance (R_D) can be varied. There is also a switch across the capacitor. Shorting out the capacitor results in an *RL* circuit instead of an *RLC* one. Last month, we saw that the *RLC* series circuit has an impedance which reached a minimum equal to the resistor value at the resonant frequency. With only the inductance present there is no resonance. Inductor impedance increases with frequency and is (ideally) zero at DC, so the *RL* circuit has a total impedance which increases from a minimum of *R* at low frequencies towards infinity at very high frequencies.

RLC and RL circuits

RLC and *RL* circuits are shown in the LTspice schematic in Fig.5. The results in Fig.6 are plots of the total resistance (applied voltage divided by current) for the two circuits. Recalling that the boost gain is inversely proportional to R_G in Fig.2 – where R_G corresponds to the total 'resistance' of the *RLC* or *RL* circuit (strictly, we should say 'impedance magnitude'). We conclude that the *RL* circuit will result in a low-pass filter with the circuit in boost mode (low resistance at low frequencies produces higher gain). In cut mode, the *RL* circuit will act as a high-pass filter (low resistance at low frequencies produces lower gain, or more attenuation). As always, with the potentiometer centred, the gain will be unity at all frequencies. For the *RLC* circuit, as we saw last month, the minimum resistance results in maximum boost gain or cut attenuation at the *LC* resonant frequency.

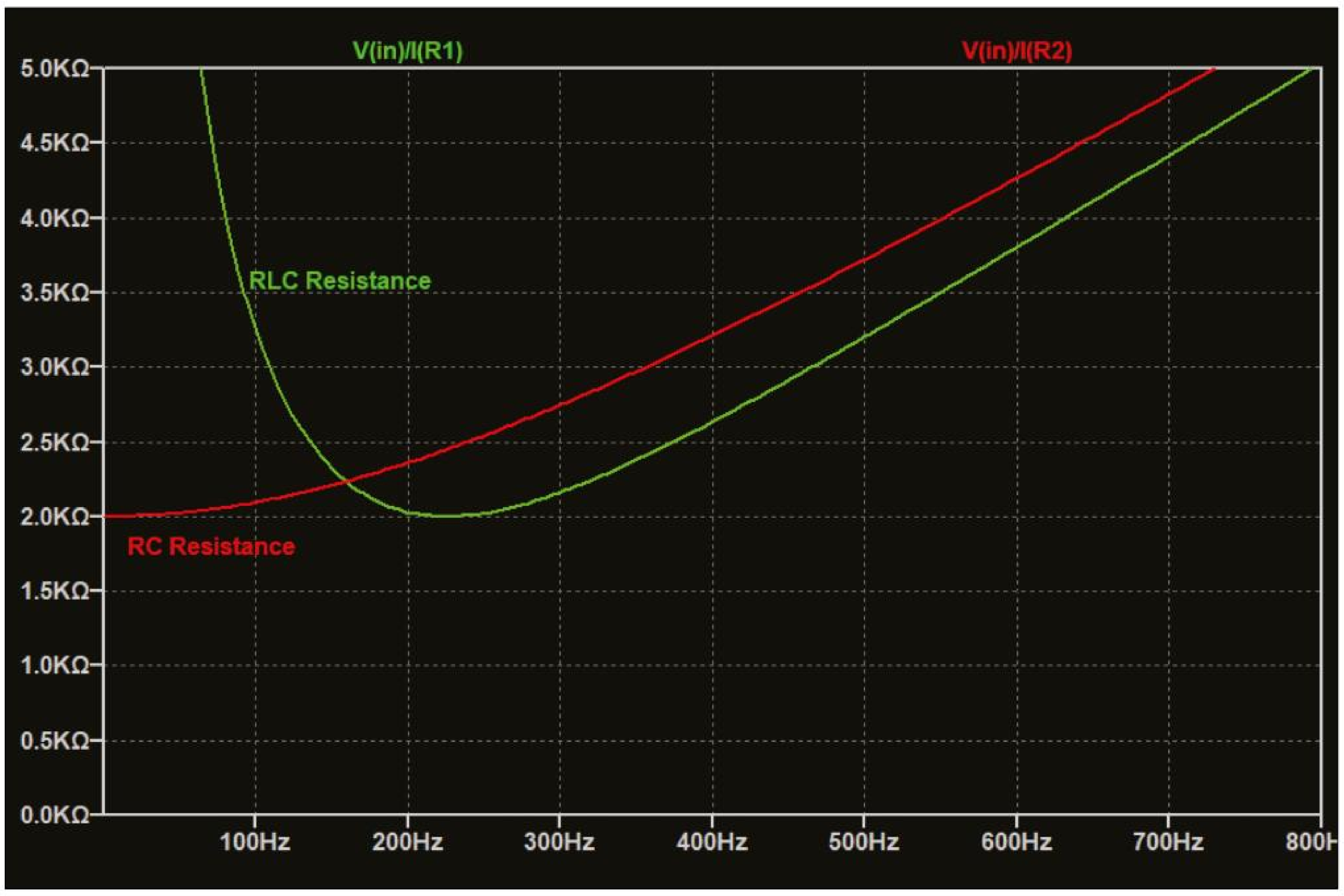


Fig.6. Simulation results showing resistance variation with frequency for *RLC* and *RL* circuits.

Changing *L* in the circuit in Fig.4 will change the centre frequency of the cut/boost notch/peak with the *RLC* circuit (SW1 open), or the cutoff frequency of the high-pass/low-pass filter with the *RL* circuit (SW1 closed). When the inductor is implemented using a gyrator, the effective inductance is set by the resistor values (as discussed in the previous articles), and we have:

$$L = (R_1 - R_2)R_2C \approx R_1R_2C$$

The approximation is based on the fact that in a typical implementation R_1 is much larger than R_2. Given that the value of R_2 is also the effective series resistance of the gyrator inductor, it makes sense to vary the effective inductance using R_1. The centre frequency (*LC* resonant frequency) of an *RLC* circuit is given by:

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

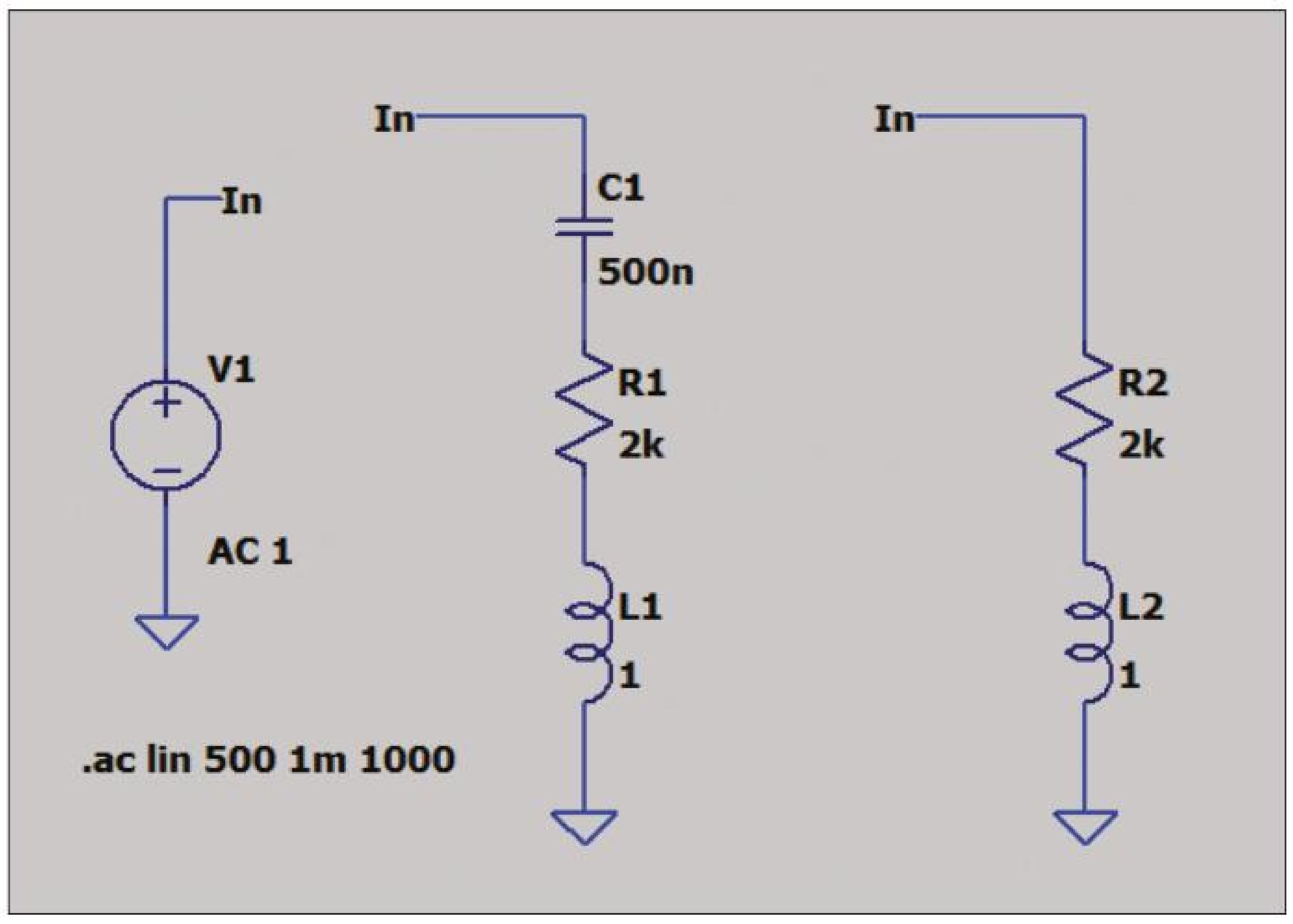


Fig.5. LTspice circuit to compare *RLC* and *RL* circuits.

Q factor

We mentioned filter *Q* (quality factor) last month, but did not discuss it in much detail. Fig.7 shows a bandpass filter response – the gain peak is at the centre frequency (f_0) and drops off on both sides. We define filter cutoff (where it is considered to block rather than pass signals) as some gain value relative to the peak (3dB below the peak is commonly used), so we have two cutoff frequencies (f_1 and f_2). The bandwidth (B_w) of the filter is the difference between the cutoff frequencies ($f_2 - f_1$). *Q* is defined as the ratio of centre frequency to bandwidth:

$$Q = \frac{f_0}{B_w}$$

A similar definition can be used for bandstop/notch filters. A high *Q* implies a sharp peak (or notch). Fig.8 illustrates the difference between relatively high-*Q* and low-*Q* bandpass filters. The *Q* for an *RLC* filter is given by:

$$Q = \frac{2\pi f_0 L}{R} = \frac{1}{R}\sqrt{\frac{L}{C}}$$

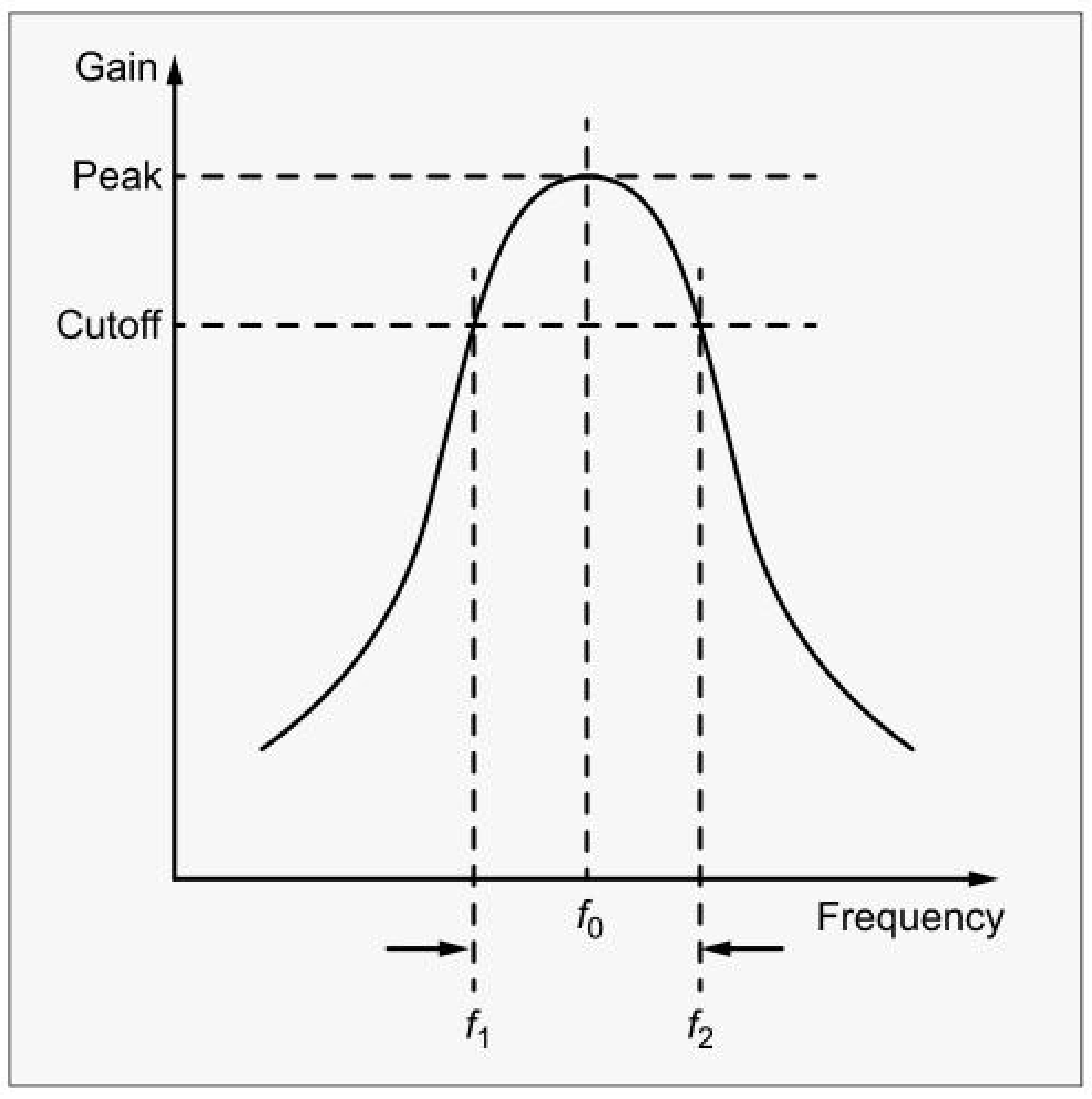


Fig.7. Bandpass filter response.

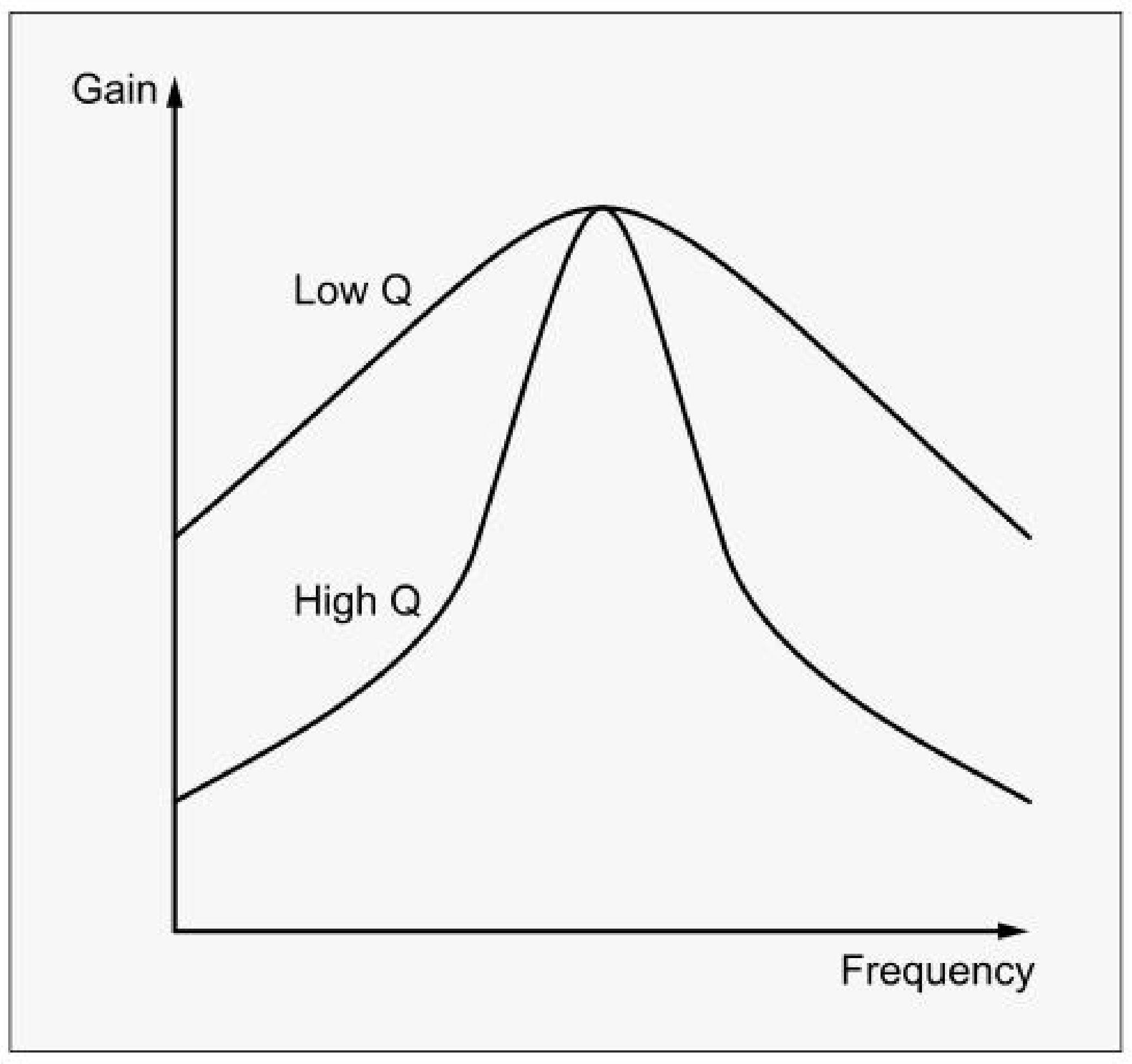


Fig.8. High and low *Q* bandpass filter responses.

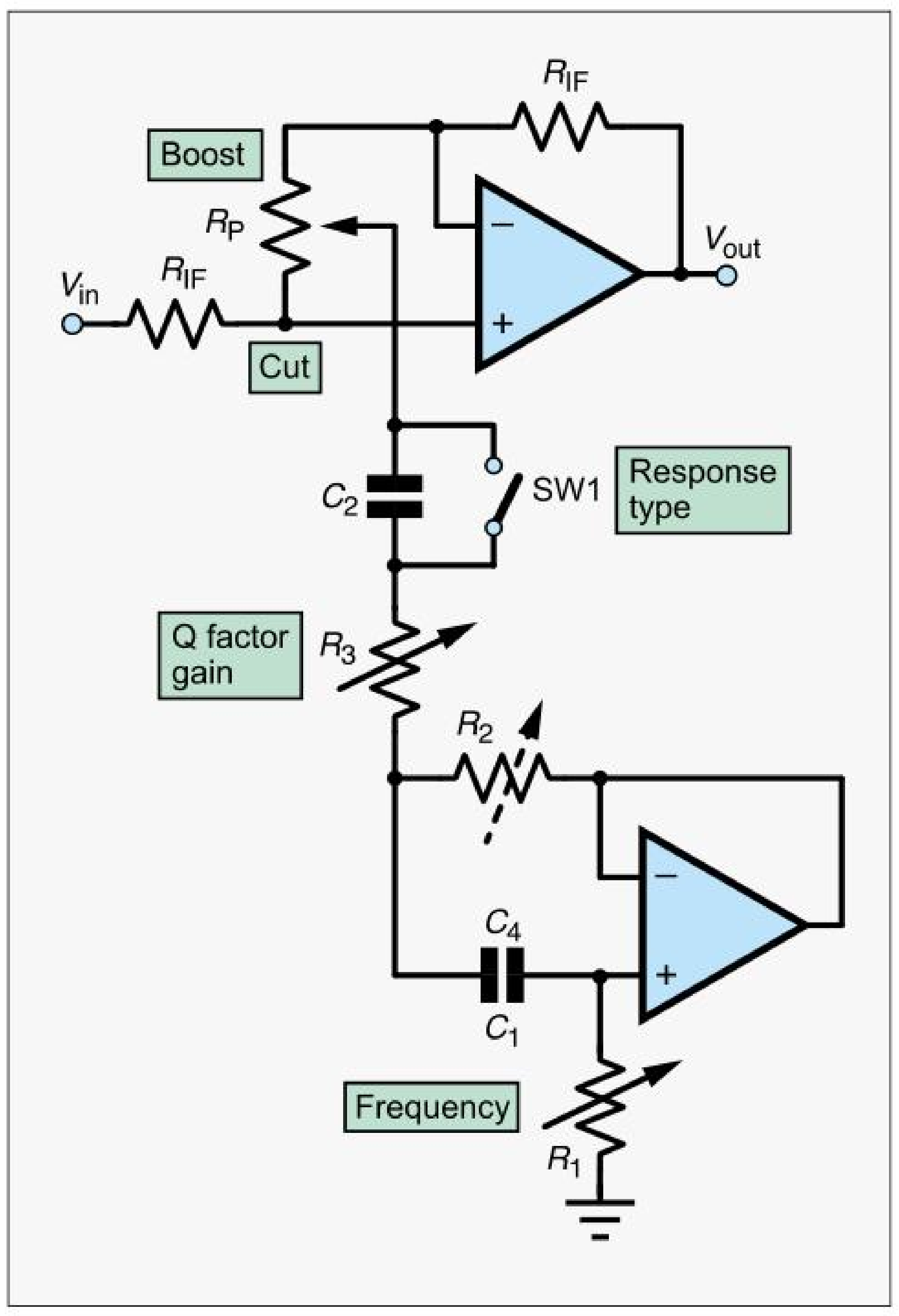


Fig.9. Gyrator-based parametric equaliser (single channel shown).

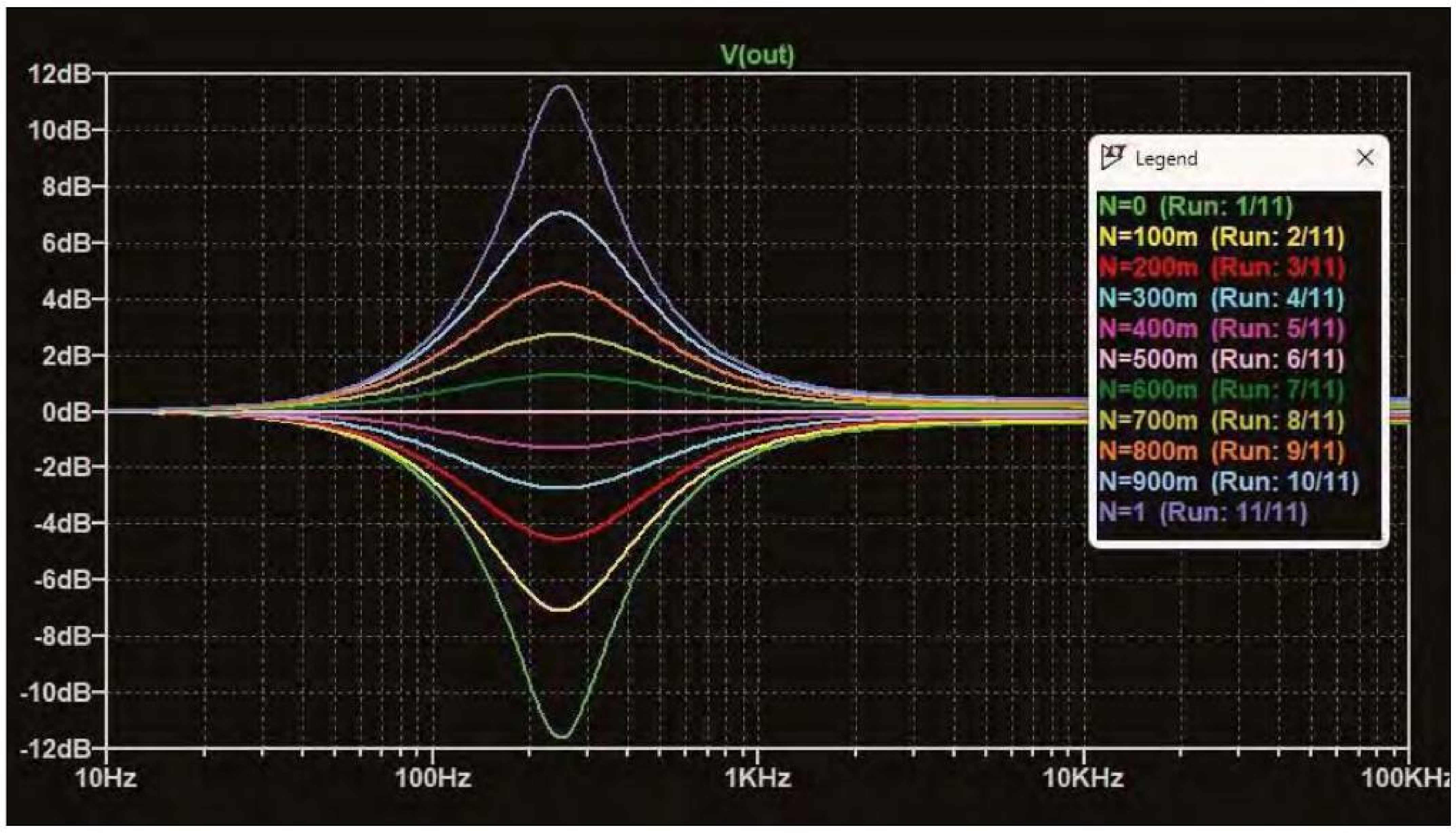
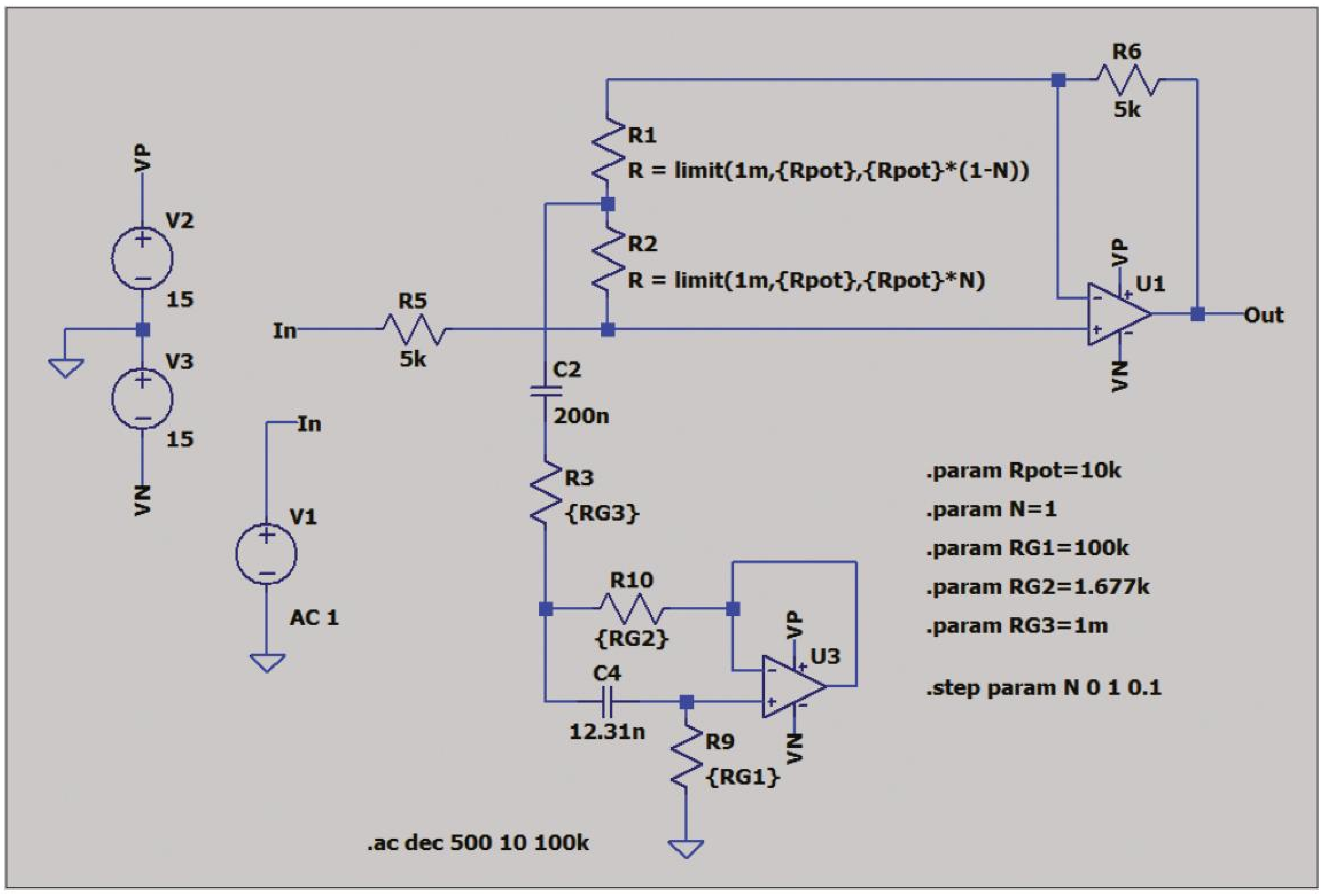


Fig.11. Simulation results from the circuit in Fig.10.



```
.param Rpot=10k
.param N=1
.param RG1=100k
.param RG2=1.677k
.param RG3=1m
.step param N 0 1 0.1
.ac dec 500 10 100k
```

Fig.10. LTspice schematic for simulating the gyrator-based parametric equaliser in Fig.9.

An ideal *LC* circuit has no resistance and therefore has infinite *Q* (from the above equations). Of course, this is not achievable in practice because all components and wiring have some resistance. However, LC circuits can achieve large *Q* values due to the fact that they exhibit resonance.

Resonance and damping

Resonance does not only occur in circuits; it is something we are aware of in everyday situations and popular culture, even if we do not always name it as such. Perhaps the most well-known, and most often quoted, examples are bells, glasses shattered by singers and children's playground swings. These can illustrate various aspects of resonant systems. The physics of resonance involves the efficient transfer of energy between different forms. For a swing (or pendulum) these are kinetic and potential energy. Capacitors and inductors both store energy (in electric and magnetic fields) and transfer the energy easily via current flow. Circuits containing just *R* and *C*, or just *R* and *L* do not show resonant behaviour because there is only one type of energy storage present.

A child on a playground swing being swung by someone is pushed once on each cycle exactly as the swing reaches its peak amplitude. If the pushing is stopped the swing will continue oscillating for a while with decaying amplitude – this is similar to the oscillation which occurs when a bell is struck. If the pushing continues we have what is known as a 'forced oscillator'. This corresponds to applying a sinewave to an *LC* circuit. In the case of a swing, if it is pushed at the right moments then the forcing frequency is at the resonant frequency and the result is a large amplitude oscillation (and hopefully a happy child). If one attempts to push a swing at the wrong times (ie, not at the resonant frequency) the oscillations will be much smaller in amplitude. This corresponds with high gain or attenuation at the resonant frequency of an *LC* circuit, which diminishes away from resonance.

The rate at which the amplitude of a swing's movement decreases when it is not pushed depends on factors such as friction and air resistance. This process is referred to as 'damping the oscillation'. If these were not present the swing could continue forever from a single push. In the *RLC* circuit the amount of damping depends on *R* – the larger the value of *R* the more damping. Damping is the reciprocal of *Q* – the

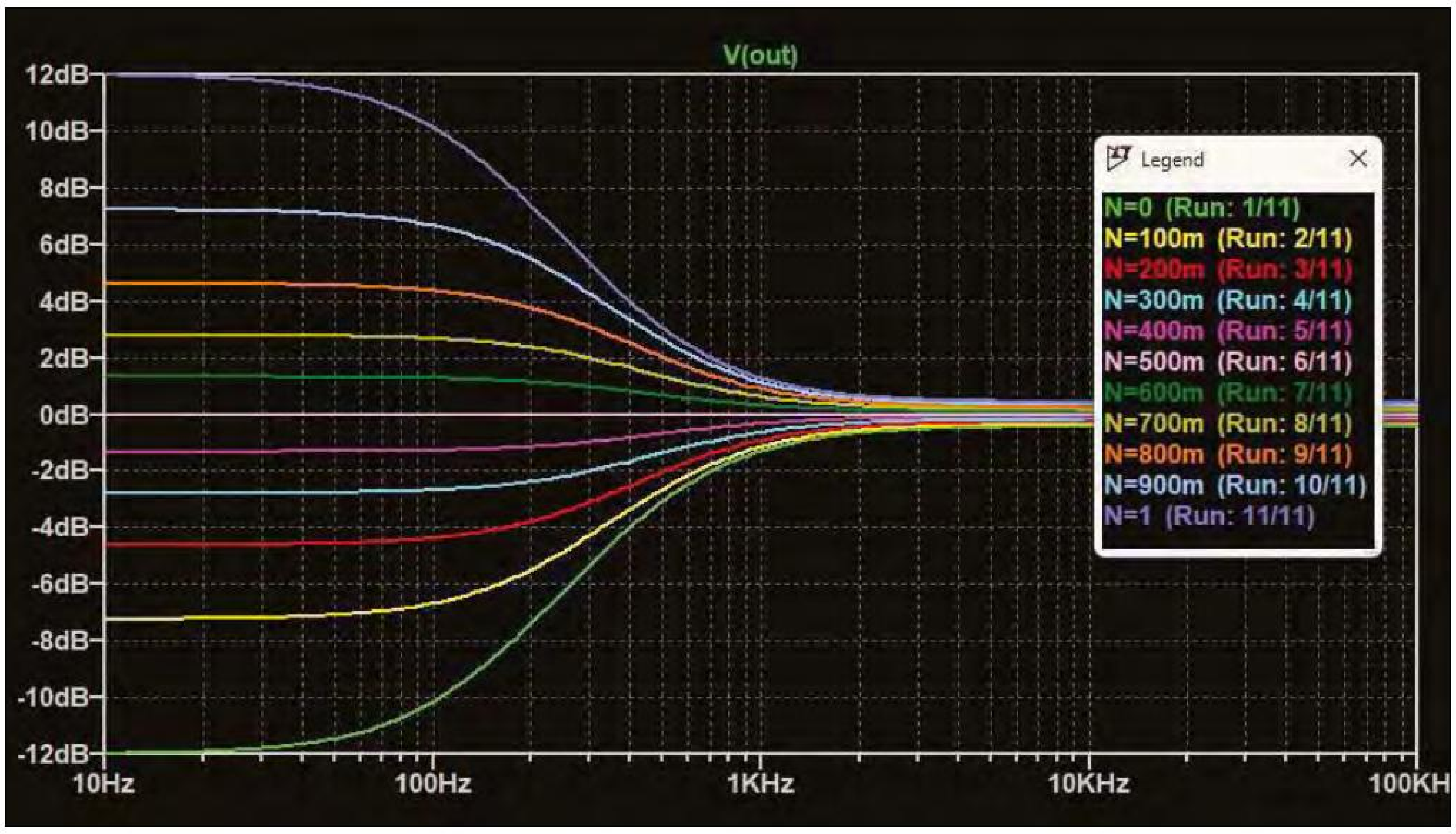


Fig.12. Simulation results from the circuit in Fig.10 with C_2 shorted.

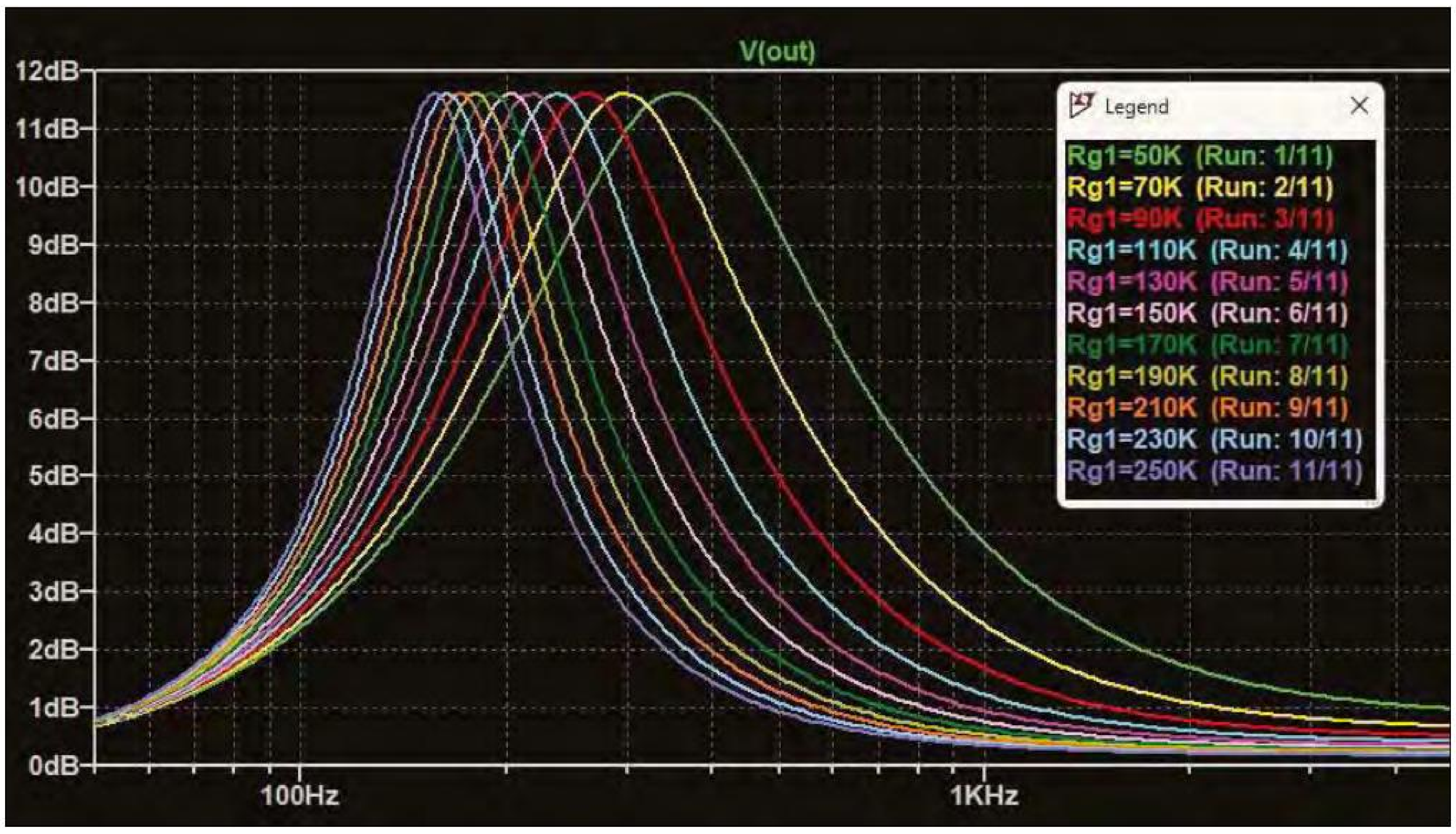


Fig.13. Simulation results from the circuit in Fig.10 showing the effect of changing the effective inductance via gyrator resistor R_{G1}.

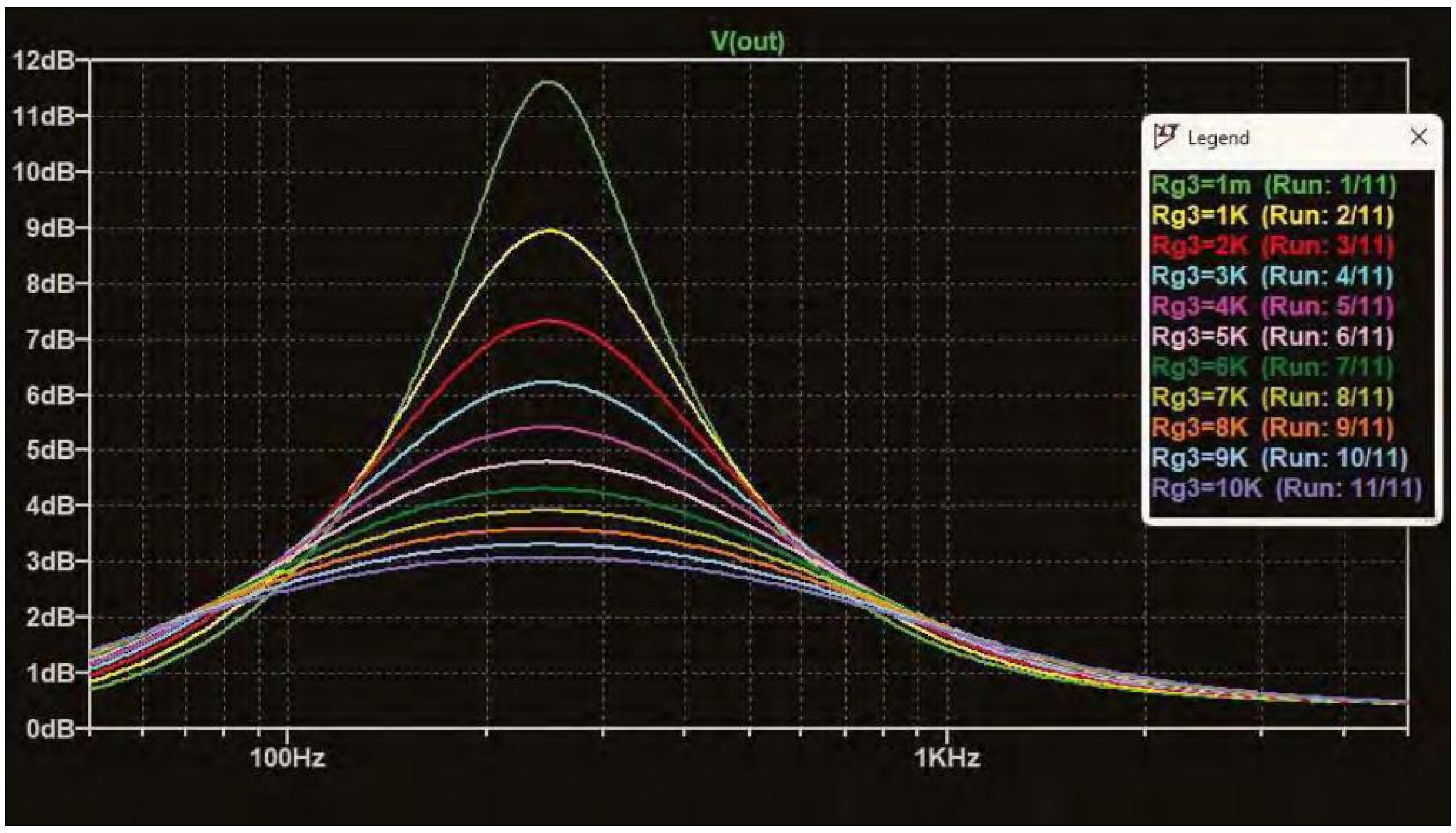


Fig.14. Simulation results from the circuit in Fig.10 showing the effect of changing the effective inductance via damping resistor R_{G3}.

equation above shows that Q is inversely proportional to R in the *RLC* circuit. In Fig.4, therefore, R_D controls the amount of damping and hence the Q of the filter.

Gyrator parametric equaliser

Fig.9 shows a gyrator-based parametric equaliser based on Fig.4 and the preceding discussion. One channel is shown, but multiple channels can be implemented using multiple copies of the potentiometer and *RLC* circuitry, as shown in Fig.3. The gyrator circuit replaces the inductor in Fig.4. R_P is the cut/boost control and operates as previously discussed. SW1 selects the peak/notch or low/highpass response type. Varying R_1 changes effective inductance and hence the centre/cutoff frequency. The Q/damping could be controlled by the gyrator's effective series resistance, which is equal to R_2. Unfortunately, R_2 also controls the effective inductance (hence frequency) and the gain, which would make the circuit difficult to adjust. Therefore, the circuit in Fig.9 has an additional series resistance R_3 which can be used to control Q, this also affects the gain, but not the frequency. This means that the effective resistance of the *RLC* circuit is $R_1 + R_3$.

Simulations

An LTSpice circuit for simulating the gyrator-based parametric equaliser is shown in Fig.10. The three resistance values in the gyrator are configured as parameters, to facilitate investigating the effect of varying them. The default value of R_{G3} is set very small compared with R_{G2} so that it has little effect in the simulation unless it is stepped to a different value (see later). The default circuit is effectively the same as the 250Hz channel in the graphic equaliser discussed last month. The response for a range of potentiometer settings (N) is shown in Fig.11. Implementation of the potentiometer in LTspice was discussed last month.

Restimulating the circuit with the capacitor shorted out results in the response shown in Fig.12. As discussed above, this produces a high-pass or low-pass response depending on R_P. The standard equation for the cutoff frequency (f_c) of an *RL* filter is:

$$f_c = \frac{R}{2\pi L}$$

The effective inductance of the gyrator is 2.03H (see last month) with R = 1.677k (= R_{G2}, the series resistance since R_{G3} is set very small), we get a cut-off frequency value of 131Hz. This is the –3dB frequency of the circuit at full boost or full cut (top and bottom traces), but not at other potentiometer settings.

Parameter stepping

Fig.13 shows how the frequency of the filter can be varied using gyrator resistor R_{G1} to vary the effective inductance. This is achieved by adding the following SPICE directive to step R_{G1} (in this case from 50kΩ to 250kΩ in 20kΩ steps).

```
.step param RG1 50k 250k 20k
```

Note that we comment out the stepping of the potentiometer setting, so that it takes the default value (N = 1, for full boost).

```
;.step param N 0 1 0.1
```

Other values of N could easily be used if required. The plot shows that the centre frequency is varied as expected, with constant peak gain, but the Q of each response is not the same.

Similarly, the plot in Fig.14 shows how the Q of the filter can be varied using the additional series (damping) resistor R_{G3}. Again, this is achieved by adding a SPICE directive to step the value of the resistor (in this case from 1mΩ (effectively zero) to 10kΩ in 1kΩ steps).

```
.step param RG3 1m 10k 1k
```

The previous `.step` statement (for R_{G1}) is commented out. The responses in Fig.14 show that varying the Q also varies the gain, but the centre frequency is constant.

By choosing the right combinations of R_{G1}, R_{G3} and N it is possible to create a set of responses with two parameters (Q, f, gain) constant, while the other is varied, but this is not necessarily easy and may only be possible over a limited range of values.

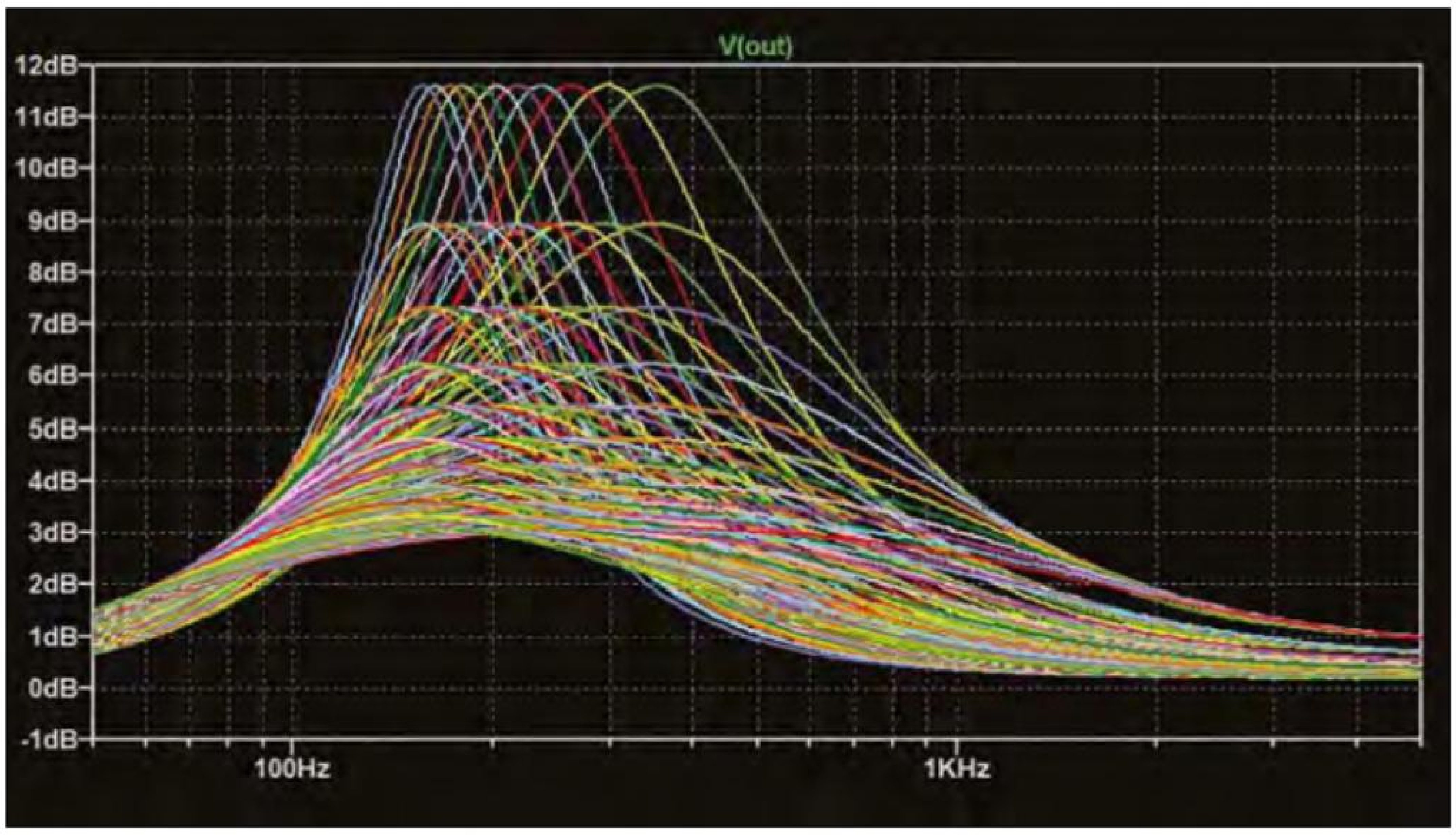


Fig.15. Simulation results from the circuit in Fig.10 stepping both R_{G1} and R_{G2}.

If you run both the R_{G1} and R_{G2} parameters stepping together then the resulting plot (Fig.15) looks a bit psychedelic and is probably not very useful as a graph, except that it illustrates the wide variety of responses which can be achieved – and this is a fixed cut/boost value, which of course can also be varied as needed. As noted last month, the very wide range of responses from parametric equalisers means they are more difficult to use effectively than graphic equalisers.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website: https://bit.ly/pe-downloads

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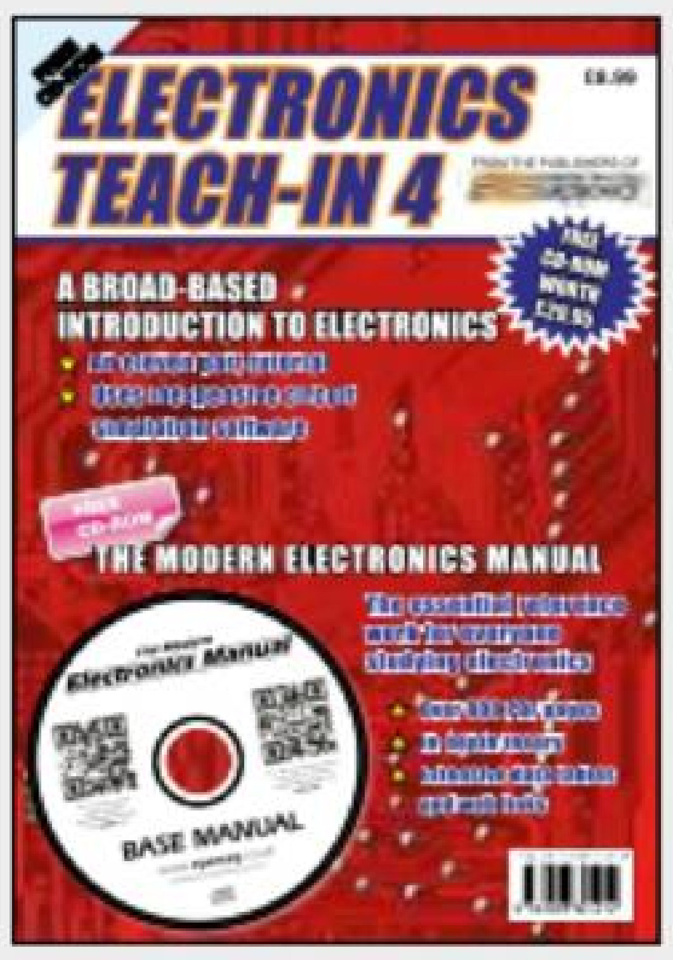

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- Pi Projects
- Pi Class
- Python Quickstart
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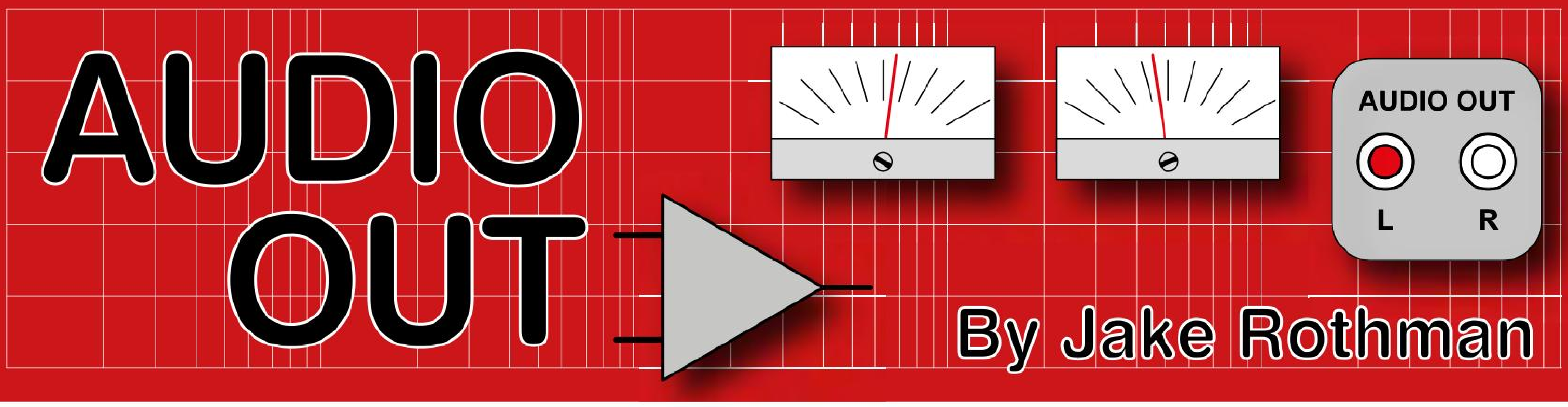
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AUDIO OUT

By Jake Rothman

Discrete audio op amp – Part 3

Over the last two issues I've covered the theory and ideas behind my *Discrete Audio Op Amp*, so now it's time to start the 'soldering bit' for a standard non-inverting x6-gain amplifier. The good news is that this is pretty easy. The 'science bit' will be testing all the possible variations and values to tweak it for your application. If you can wait, I intend to use this discrete op amp as an optimised module in many specialised audio designs.

In this article I have provided construction details for three variations. First, the standard low power ±25V, 600Ω version, and then two high-power types using extra output transistors. One is a high-voltage ±25V, 180Ω version and the other is a low-voltage ±12V, 30-150Ω design, mainly for headphones. Last, but not least, I've included plenty of R&D data for experimenters and tinkerers.

Components list

Added components marked * are for the high-power ±25V, 180Ω version. Values for the low-impedance design are given separately later.

Resistors

All 1% metal film 0.25W, otherwise 5%, for non-critical devices.

R1,2	180Ω 1%
R3,4	330Ω 1%
R5	470Ω 5%
R6	2.2kΩ 5%
R7	10kΩ 5%
R8	220Ω 5%
R9	6.8kΩ 5%
R10	3.9kΩ 5%
R11,12	12Ω 1% (2.2Ω 5%*)
R13	2.7kΩ 5%
R14	1.5kΩ 5%
R15	43kΩ 5%
R16	5.6kΩ 5%
R17	47kΩ 5%
R18	22kΩ 1%
R19	1kΩ 1%
R20	4.3kΩ 1%
R21	22kΩ 1%
R22	47Ω 5%
R23	100k Ω 5%
R24,25	link (560Ω 5%*)
R26	3.3kΩ 1%
R27	330Ω 5% (link for max headroom, insert for best PSRR)

PR1, 2	5kΩ miniature 5mm round preset Bourns 3321H

Capacitors

All 20% tolerance unless otherwise stated.

C1	220nF, ceramic 2.5mm X7R
C2	1μF, tantalum bead 10V
C3	39pF, 5mm NP0 5% / 47pF*
C4	10μF, tantalum bead 10V
C5	100nF, ceramic 5mm X7R
C6 1μF	tantalum 35V
C7 4.7μF	electrolytic 35V
C8 150pF	ceramic 5mm NP0 5%
C9 100μF	electrolytic 10V
C10 100μF	electrolytic 25V
C11 10pF	ceramic 5mm NP0 5%
C12 47pF	5mm NP0 5% / 22pF*
C13 680pF	polypropylene 10%
C14 10μF	electrolytic 25V
C15	100pF, ceramic 2.5mm NP0 5%*

Semiconductors

TR1,2,6,7,8,9,12	BC546B NPN small-signal medium-voltage
TR3,4,5,10,11	BC556B PNP small-signal medium-voltage
TR13	BD140, NPN high-voltage power*
TR14	BD139, PNP high-voltage power*
LED1	red, low-current 5mm

Miscellaneous

L1 3.9-15μH axial inductor 20%

20ºC/W heatsinks plus M3 nuts, bolts and washers x2*

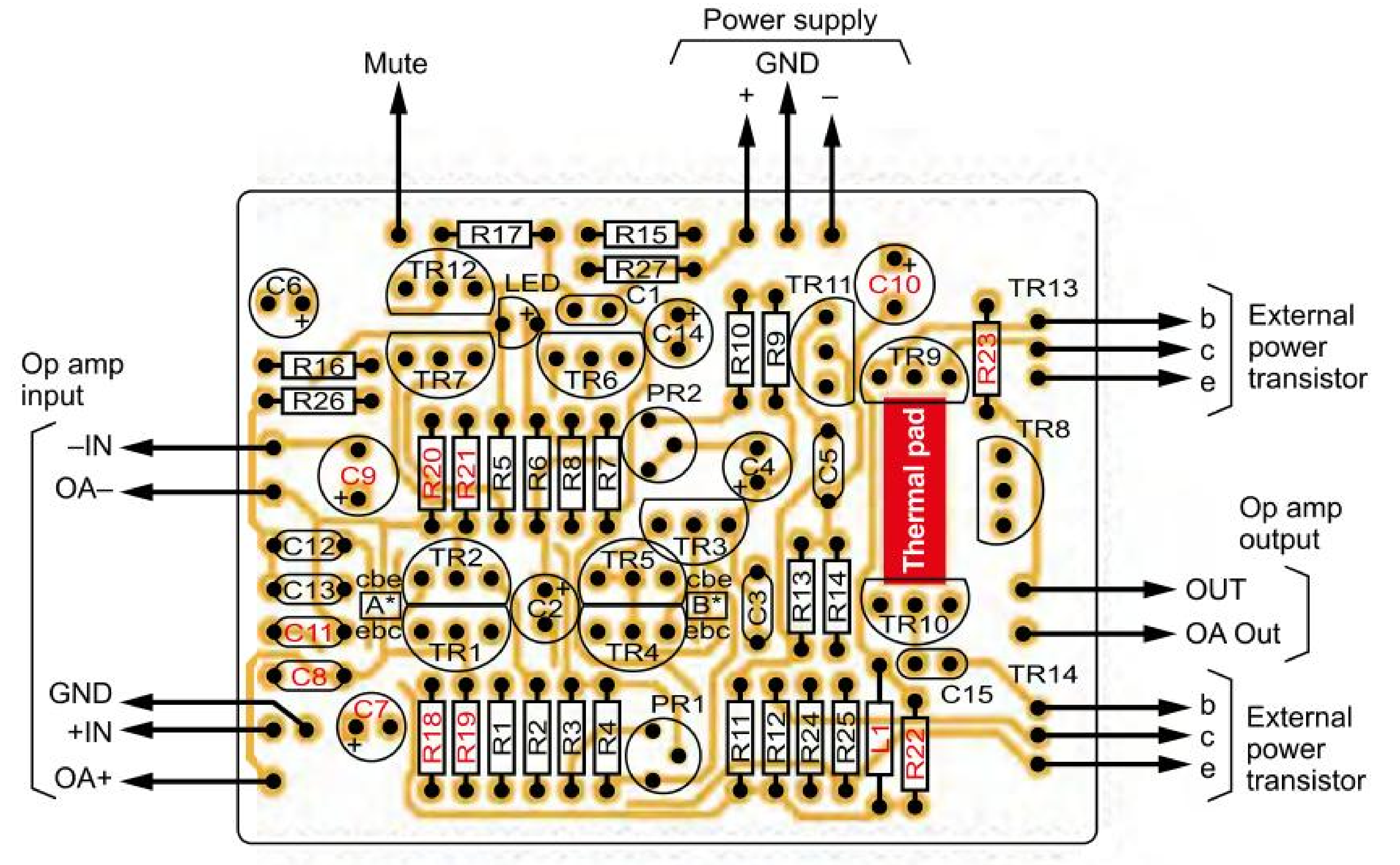
0.1-inch single-sided terminal pins x7

0.35-inch wire links (low power only) x2

Low impedance, low-voltage option

Changes to above are as follows:

R8	110Ω 5%
R9	5.6kΩ 5%
R11,12	1Ω 5%


Power supply
GND
+
–
Mute
Op amp input
–IN
OA–
GND
+IN
OA+
R17
R15
R27
TR12
LED
C1
C6
C14
TR11
C10
TR13
R16
R26
TR7
TR6
PR2
R10
R9
TR9
R23
TR8
b
c
e
External power transistor
C9
R20
R21
R5
R6
R8
R7
C4
C5
Thermal pad
Op amp output
C12
C13
C11
C8
TR2
TR5
TR3
cbe
A*
B*
ebc
C2
C3
R13
R14
TR10
TR1
TR4
OUT
OA Out
C7
R18
R19
R1
R2
R3
R4
PR1
R11
R12
R24
R25
L1
R22
C15
TR14
b
c
e
External power transistor

Notes
Op amp components have black labels
External components have red labels
'OA' denotes op amp connections
'–IN', '+IN' and 'OUT' are audio connections

SMD dual transistors
If you are using dual bipolar transistors instead of through-hole devices then:
*A is for TR1 and TR2 – see Fig.23 in Part 2.
*B is for TR4 and TR5 – see Fig.23 in Part 2.

Fig.35. PCB overlay for the discrete op amp – insert all components for the non-inverting amplifier. Feed the input into +in and use the OUT pin. (Note there are a few minor changes from the version 1 PCB shown in Fig.16 in *Part 2*) C12 and C13 were reverse numbered, R27 and C15 added).

R24,25	220Ω 5%
R10	6.2kΩ 5%
R15	6.8kΩ 5%
R26	*omit*
R27	100Ω 5%
C3	100pF 5% NP0 ceramic
C9	100µF 16V bi-polar electrolytic, Suntan CD71 or equivalent.
C10	220µF 16V bi-polar electrolytic, Suntan CD71 or equivalent. Omit for DC coupling.
C12,13,15	*omit*
C14	100µF 16V electrolytic
TR1,2,6,7,12	BC549C NPN small-signal low-noise
TR3	MPSA63/4 PNP small-signal Darlington
TR4,5,11	BC559C small-signal low-noise
TR8,9	BC337 NPN medium-power
TR10	BC327 PNP medium-power
TR13	BD436 PNP power
TR14	BD435 NPN power
L1	14µH, low-Z choke

PCBs and kits containing the harder-to-find parts for the basic *Discrete Op Amp* are available from the *PE PCB Service* – **www.electronpublishing.com**

Remember, that all parts, including any unusual ones mentioned in these articles are available separately from the *AO Shop* – see advert on p.64.

PCB stuffing

If you are using the SMT transistors on the input stage, solder these first; you don't want other components getting in the way. If you're making the low-power version, fit wire links into positions R24 and R25. Although it's normal practice to solder semiconductors last, I think it's best to fit the output transistor TR9 and TR10 along with the associated temperature-tracking bias transistor TR8 on the thermally conductive pad while the space around is clear. A bit of thermal paste under the transistors is a good idea. Bend, position and hold them down flat before soldering. Fig.35 shows the overlay for the x6-gain non-inverting amplifier.

Fig.36 and Fig.37 show how to configure the PCB for the standard inverting and differential configurations respectively, as described in *Part 2*. To make a buffer, just link R21 and leave out the other feedback parts, C9 and R20.

Power op amp

The output current and hence power of the op amp can be increased by adding an extra pair of output transistors, TR13 and TR14. These are coupled to the original output transistors by adding 560Ω collector load resistors, R24 and R25. This forms a complementary follower pair (CFP) output. This means we don't need thermal sensing on the output transistors, as we would if a second push-pull emitter-follower stage was added on. Make sure the metal part of the transistor case faces inwards to the board, as shown in Fig.38. Small heatsinks are a good idea, such as those shown in Fig.39.

The emitter resistors R11 and R12 are reduced to 2.2Ω for the high-power op amp, so more current can be delivered. The quiescent current has to be set to a minimum of 13mA for low distortion, giving 30mV across the resistors. The distortion curve is shown in Fig.40.

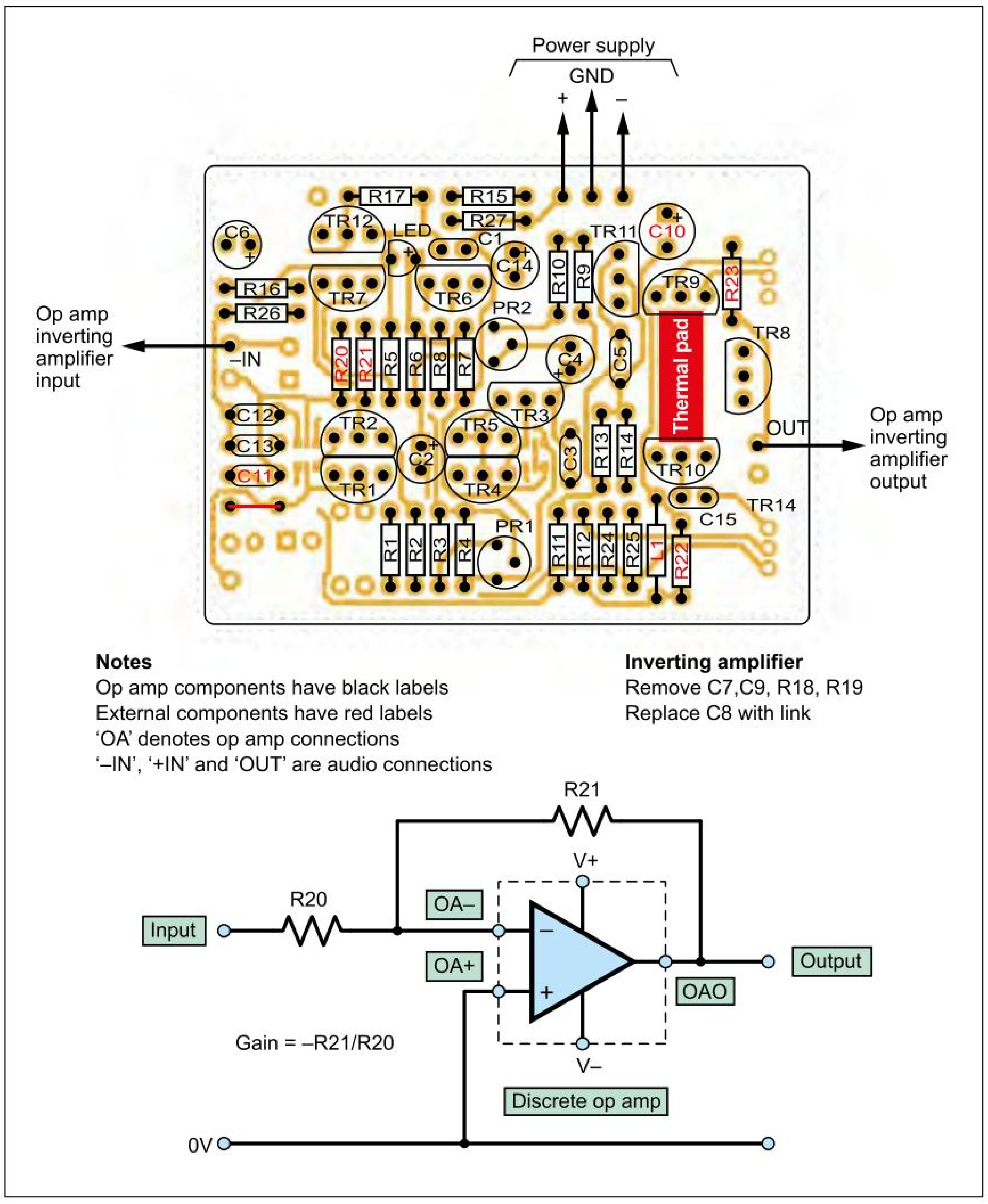
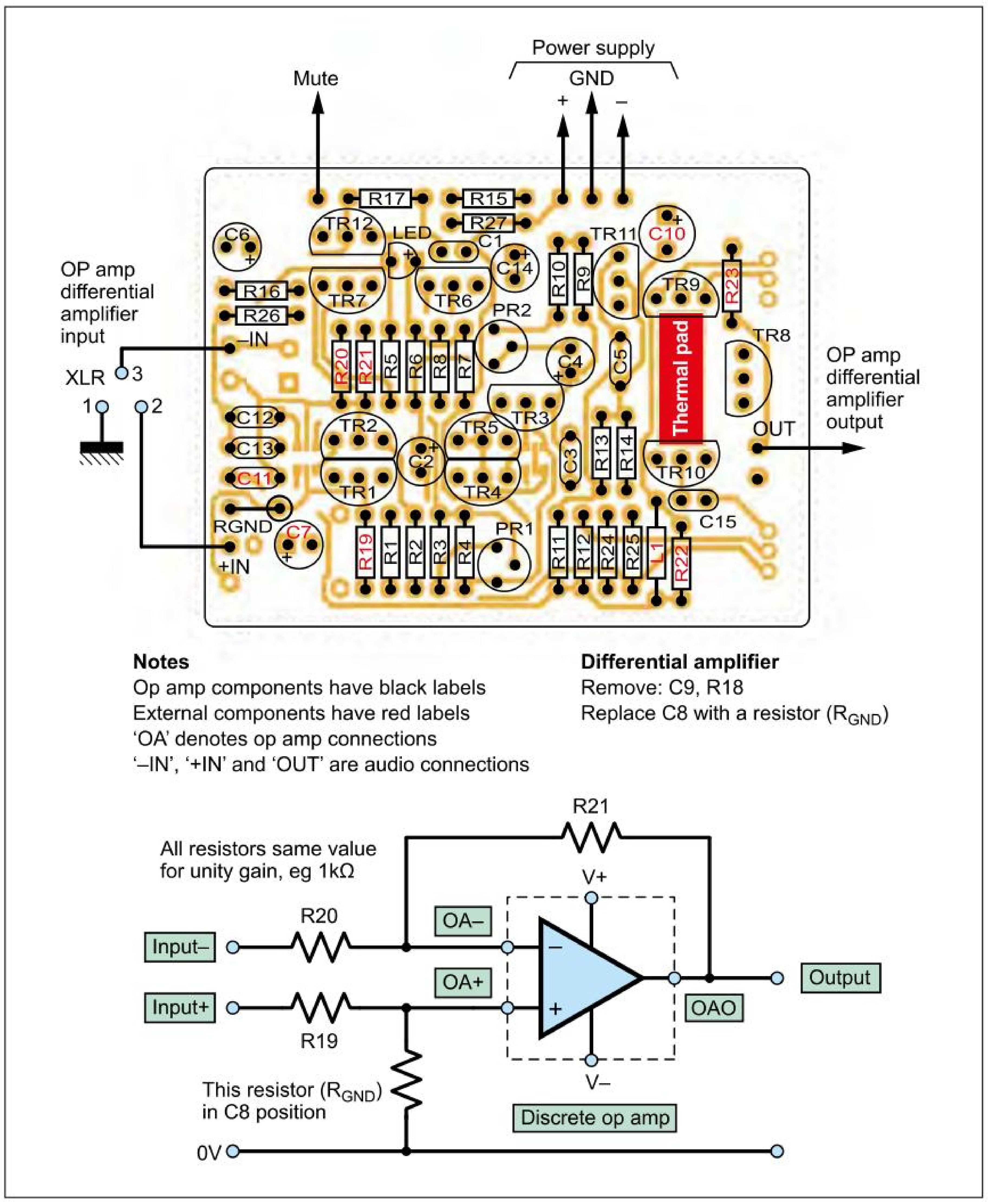

Power supply
GND
+
–
Op amp inverting amplifier input
–IN
Op amp inverting amplifier output
OUT
Thermal pad
R17
R15
R27
TR12
LED
C1
C6
C10
TR11
C14
R16
R26
TR7
TR6
PR2
R10
R9
TR9
R23
TR8
R20
R21
R5
R6
R8
R7
C4
C5
C12
C13
C11
TR2
TR1
C2
TR5
TR3
TR4
C3
R13
R14
TR10
C15
TR14
R1
R2
R3
R4
PR1
R11
R12
R24
R25
L1
R22
Notes
Op amp components have black labels
External components have red labels
'OA' denotes op amp connections
'–IN', '+IN' and 'OUT' are audio connections
Inverting amplifier
Remove C7,C9, R18, R19
Replace C8 with link
R21
V+
R20
OA–
Input
OA+
Output
OAO
Gain = –R21/R20
V–
Discrete op amp
0V

Fig.36.(above) Discrete op amp inverting amplifier connections.

Fig.37. (below) Discrete op amp differential amplifier connections.


Power supply
GND
+
–
Mute
OP amp differential amplifier input
–IN
XLR
3
1
2
OP amp differential amplifier output
OUT
Thermal pad
RGND
C7
+IN
R19
R17
R15
R27
TR12
LED
C1
C6
C10
TR11
C14
R16
R26
TR7
TR6
PR2
R10
R9
TR9
R23
TR8
R20
R21
R5
R6
R8
R7
C4
C5
C12
C13
C11
TR2
TR1
C2
TR5
TR3
TR4
C3
R13
R14
TR10
C15
R1
R2
R3
R4
PR1
R11
R12
R24
R25
L1
R22
Notes
Op amp components have black labels
External components have red labels
'OA' denotes op amp connections
'–IN', '+IN' and 'OUT' are audio connections
Differential amplifier
Remove: C9, R18
Replace C8 with a resistor (R_{GND})
All resistors same value for unity gain, eg 1kΩ
R21
V+
R20
OA–
Input–
OA+
Input+
R19
Output
OAO
This resistor (RGND) in C8 position
V–
Discrete op amp
0V

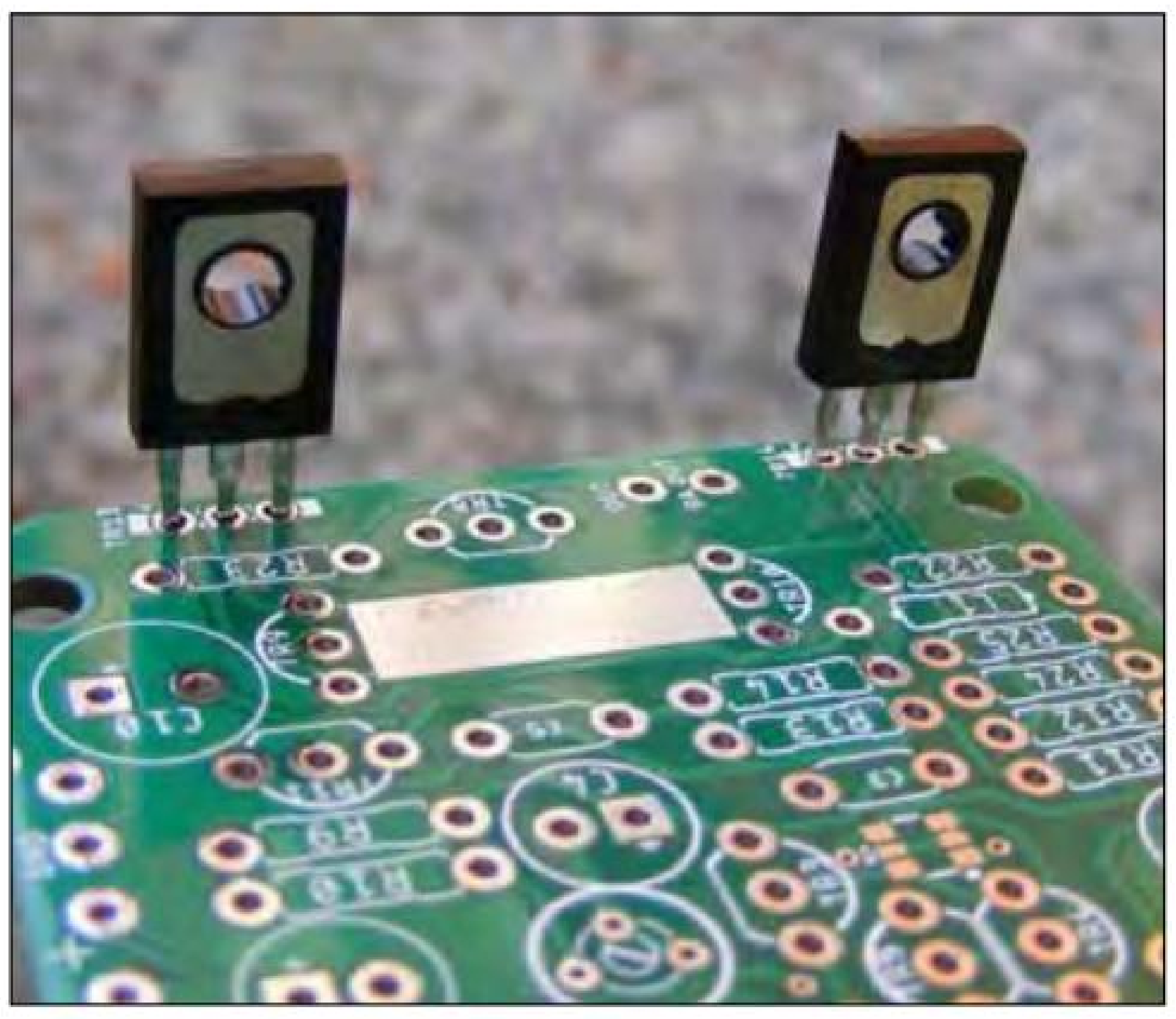


Fig.38. TO126 transistor orientation – note PNP is on the left, NPN on the right.

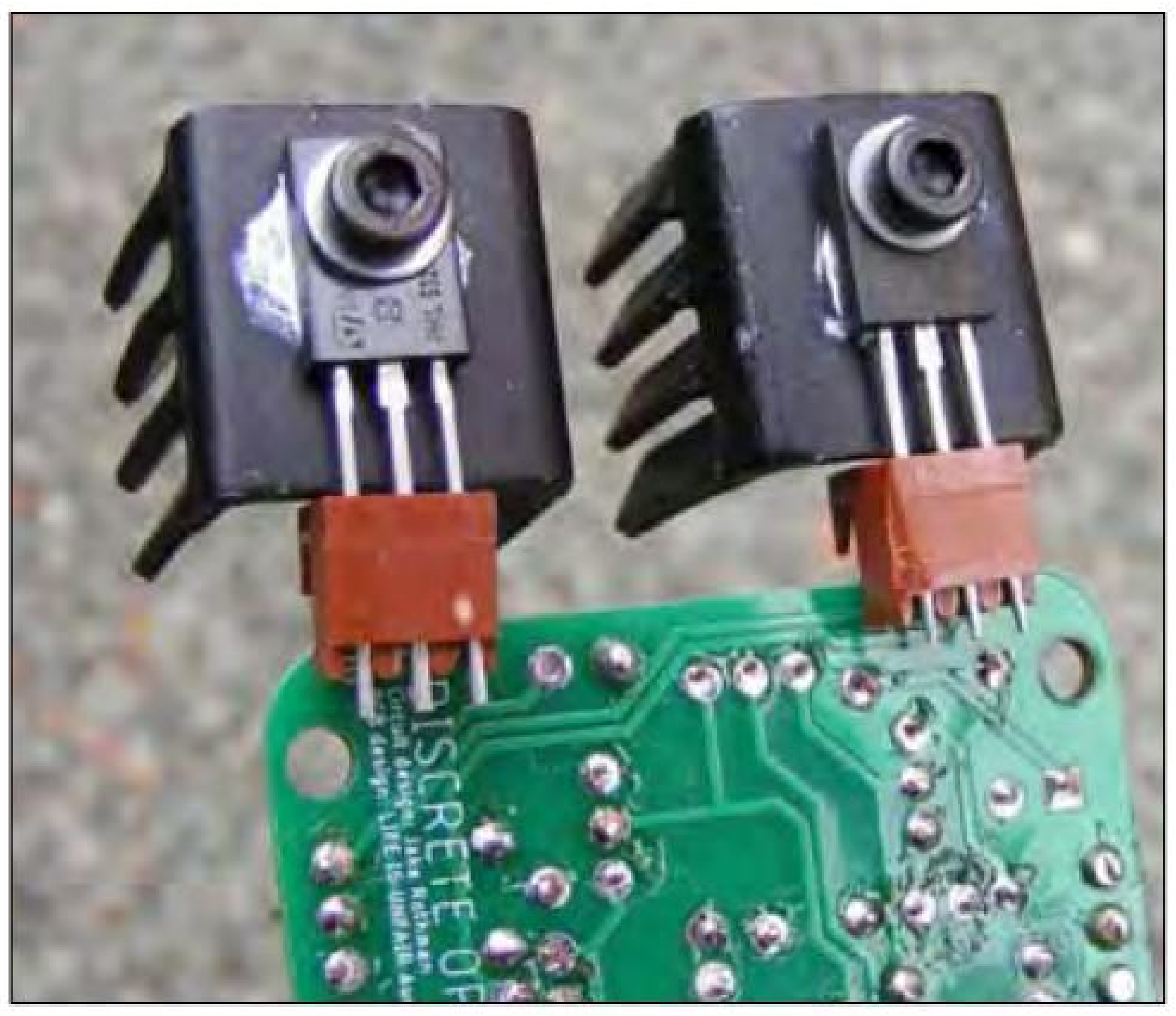


Fig.39. Heatsinks are needed for high-power low-impedance operation.

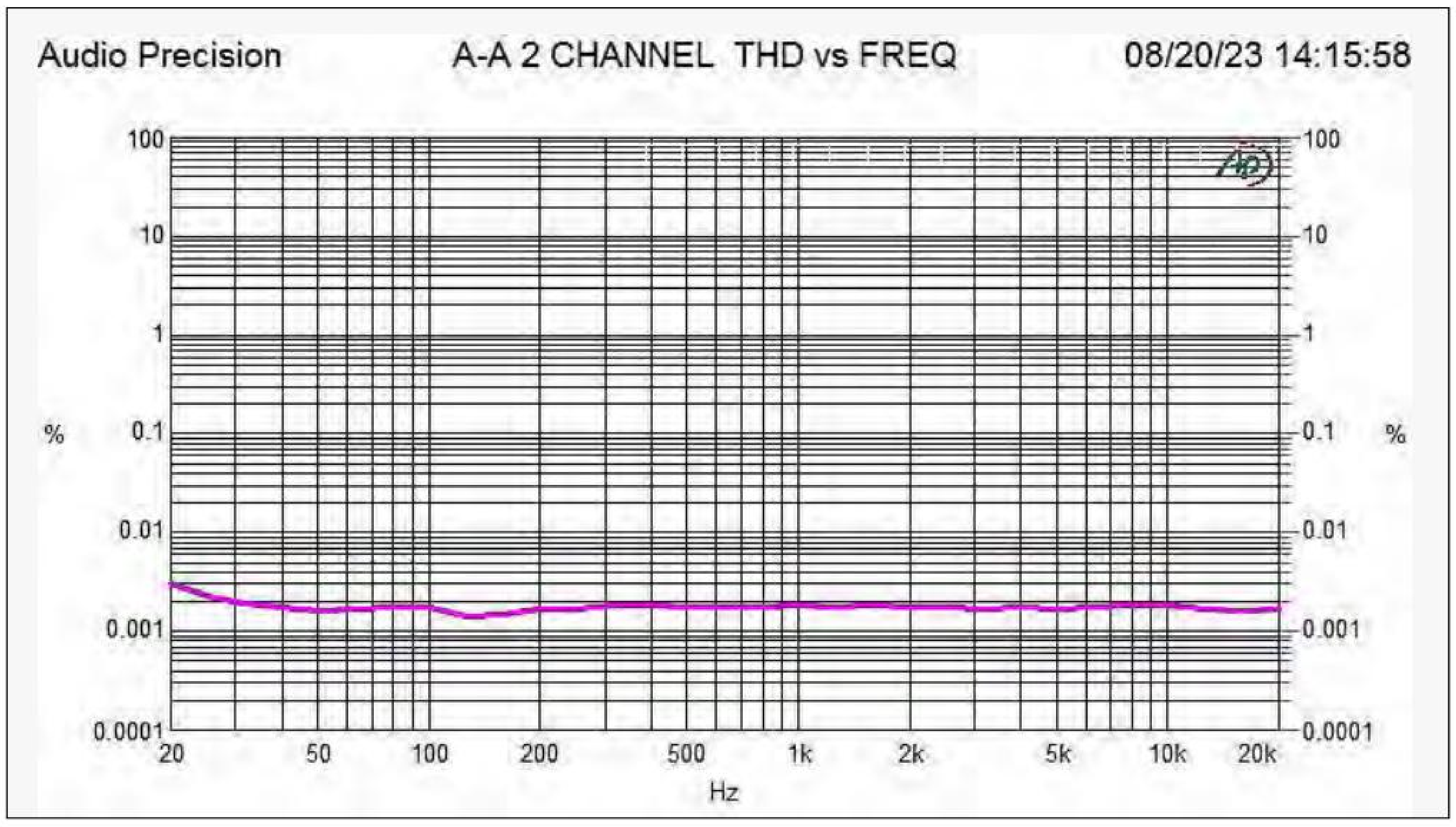


Fig.40. Distortion curve for high-power version of the discrete op amp using MJE243/53 output transistors (TR13 and TR14). Ratings are: ±25V, 180Ω load, $8V_{pk-pk}$.

Instability and compensation

Adding an extra set of output transistors increases the open-loop high frequency loss and phase shift. This can cause oscillation when negative feedback is applied unless the compensation is optimised. The main problem with the CFP configuration is that each driver and output transistor pair have their own individual feedback loop. This loop itself can sometimes become unstable. The low-cost, ever popular BD139/140 pair commonly used in discrete op amp outputs can be unstable, which was the case here.

One problem is that the PNP BD140 (TR13) is slower, having a transition frequency (F_t – where the gain falls to one) of 70MHz, compared to the BD139 (TR14), which is 250MHz. I suspect this is the cause of the negative side of the cycle bursting into oscillation, a common problem with CFP stages. It is usually fixed by adding a 100pF capacitor (C15) across the base-collector junction of the driver transistor (TR10), slowing down the negative section of the output stage to match the positive side. Further tweaking was also done to the compensation, with C3 increased to 47pF and C12 decreased to 22pF; basically, the inclusive Baxandall second-order compensation had to be reduced. The distortion was the same in the higher-power option as the lower-power version with most transistors, except the BD139/40 which gave around 0.004%, compared to 0.002% for the lower-power version

The board is not designed for standard second-order compensation, as shown in Fig.27 last month. However, if you want to experiment, it can be connected as shown in Fig.41.

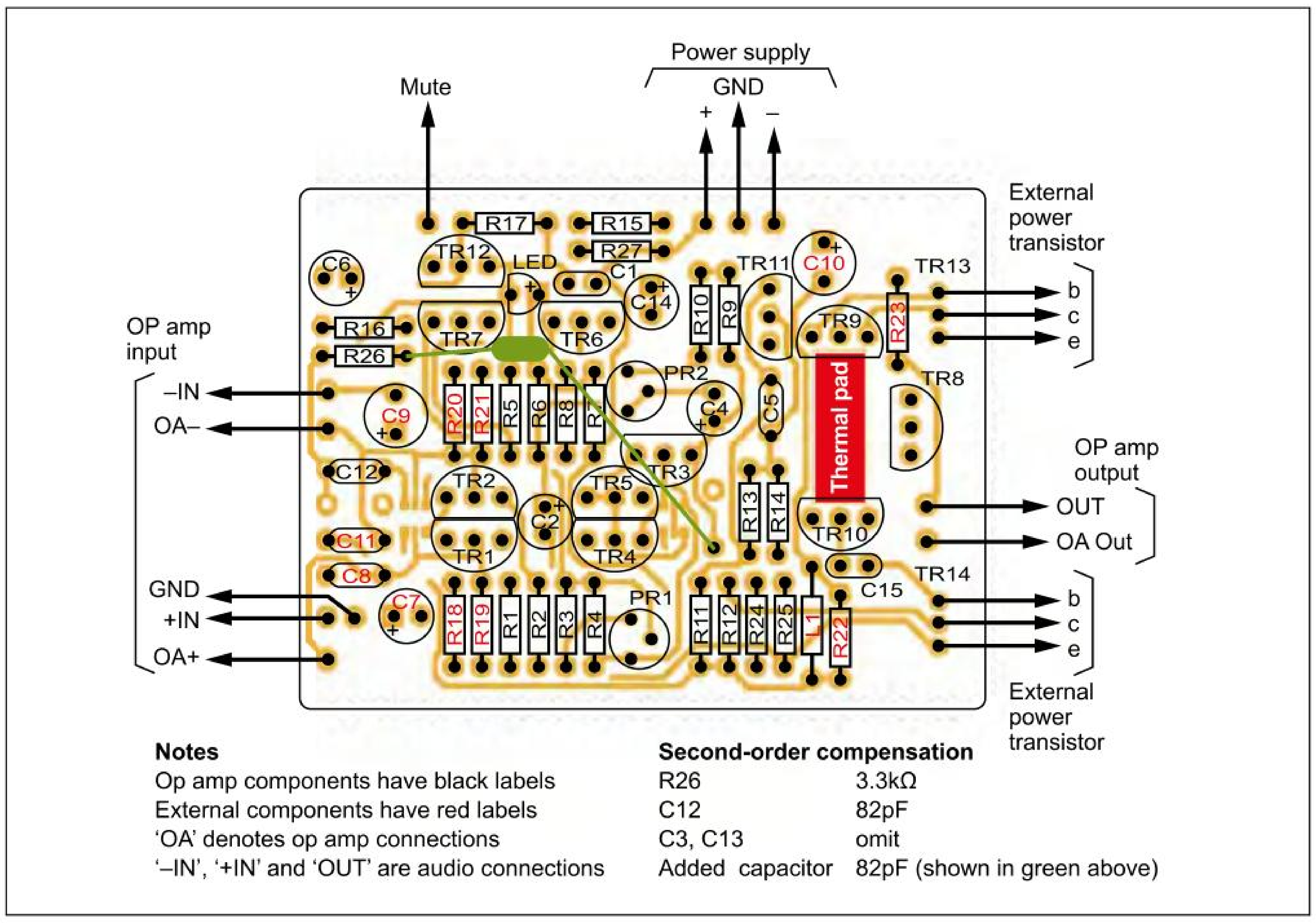
Headphone amplifiers

This is possibly the most important application for the discrete audio op amp. The standard output transistors are fine for traditional high-impedance headphones, such as the 600Ω Sennheiser HD480s. The common Beyerdynamic DT150 studio headphones are normally 250Ω, so these will need the extra output transistors. Some more recent studio headphones, such as the Beyerdynamic DT770 can be as low as 32Ω or 80Ω, which will need a high-current output. Low-voltage rails are also a good idea here, using ±25V rails would render most, including my lovely 50Ω Sennheiser HD515s, open circuit in microseconds.

When increasing the current output it is usually necessary to increase the VAS current to avoid premature clipping on the negative cycle. This can easily be done by reducing R8 to 110Ω, increasing the current to 9mA. It's also necessary to increase the quiescent current to 50mA, by adjusting PR1. Cheap low-voltage output transistors can be used, such as the BD135/6.

Many headphone amplifiers use an output series resistor of 100Ω to equalise the power between different impedances and give extra short-circuit protection. This is important because shorts often occur in the jack plug. This resistor is also a good idea with the high-power op amp, since these headphones only need about $3V_{rms}$ for full volume.

Warning: using a high-voltage amp with sensitive headphones, such as the famous



Notes
Op amp components have black labels
External components have red labels
'OA' denotes op amp connections
'–IN', '+IN' and 'OUT' are audio connections

Second-order compensation	
R26	3.3kΩ
C12	82pF
C3, C13	omit
Added capacitor	82pF (shown in green above)

Fig.41. Second-order compensation can just about be added, but it's a 'bit messy'. It is an interesting experiment for tinkerers though.

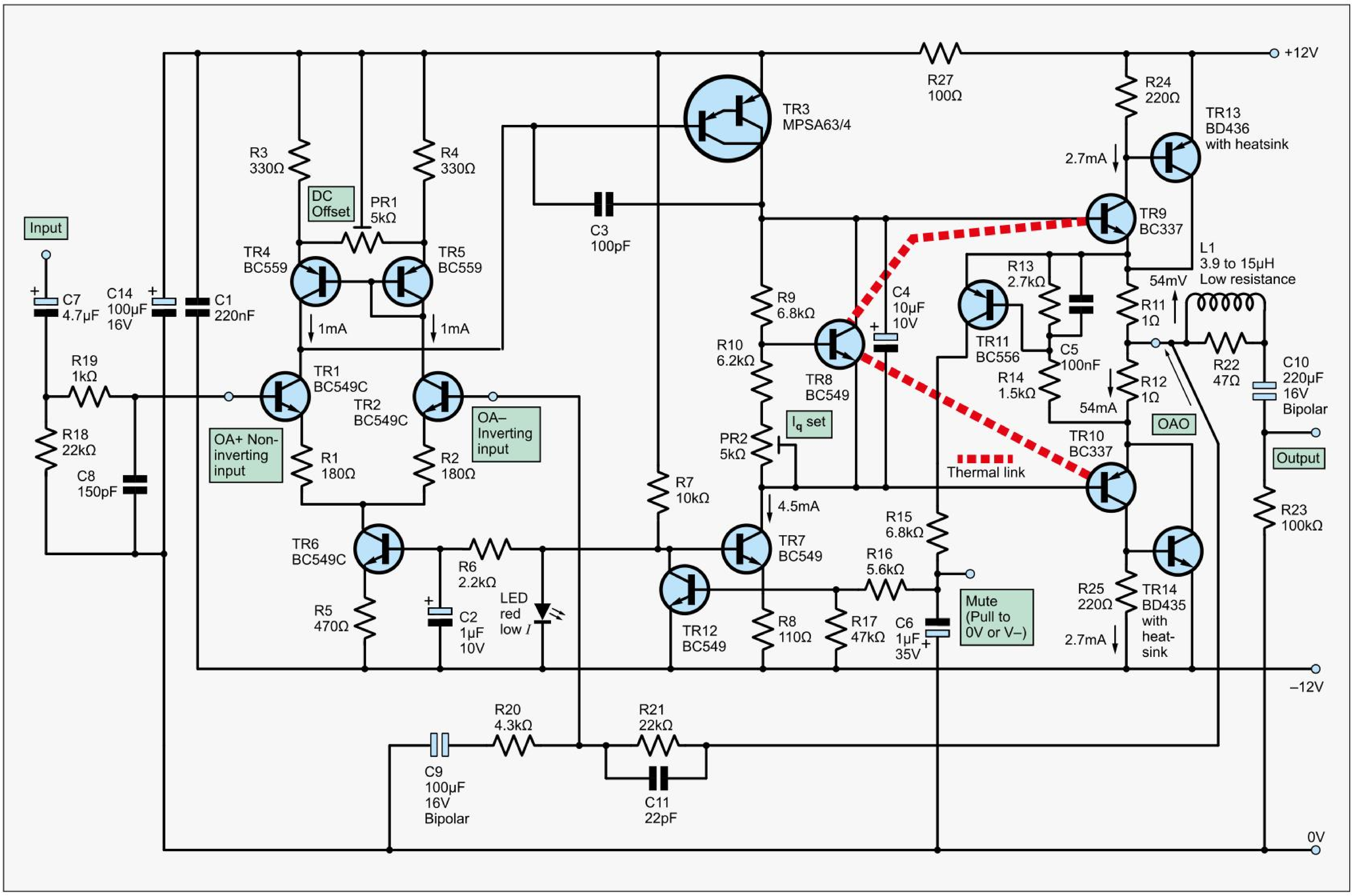

+12V
R27
100Ω
R24
220Ω
TR13
BD436
with heatsink
TR3
MPSA63/4
R3
330Ω
R4
330Ω
DC
Offset
PR1
5kΩ
C3
100pF
2.7mA
TR9
BC337
Input
TR4
BC559
TR5
BC559
R13
2.7kΩ
L1
3.9 to 15μH
Low resistance
54mV
C7
4.7μF
C14
100μF
16V
C1
220nF
R9
6.8kΩ
C4
10μF
10V
R11
1Ω
1mA
1mA
R10
6.2kΩ
TR11
BC556
C5
100nF
R22
47Ω
C10
220μF
16V
Bipolar
R19
1kΩ
TR1
BC549C
TR8
BC549
R14
1.5kΩ
R12
1Ω
TR2
BC549C
54mA
OAO
R18
22kΩ
OA+ Non-
inverting
input
OA–
Inverting
input
Iq set
PR2
5kΩ
TR10
BC337
C8
150pF
R1
180Ω
R2
180Ω
Thermal link
Output
R7
10kΩ
R23
100kΩ
4.5mA
R15
6.8kΩ
TR6
BC549C
TR7
BC549
R16
5.6kΩ
R6
2.2kΩ
R25
220Ω
TR14
BD435
with
heat-
sink
R5
470Ω
C2
1μF
10V
LED
red
low I
TR12
BC549
R8
110Ω
R17
47kΩ
C6
1μF
35V
Mute
(Pull to
0V or V–)
2.7mA
–12V
R20
4.3kΩ
R21
22kΩ
C9
100μF
16V
Bipolar
C11
22pF
0V

Fig.42. Low-impedance 32Ω headphone op amp driver circuit. Note the use of a Darlington transistor for TR3 and value changes

white 400Ω DT100 headphones used by musicians in studios for decades, can cause noise-induced hearing damage. I know, I now have severe high frequency loss from recording vocals with them.

Low-impedance version

Op amps have a similar circuit topology to power amps, which are basically op amps which can drive low impedances. In other words, it's easy to use this PCB to build mini power amps. The low-cost BD135/6 output transistors are useful for synthesisers, spring-line drivers, low-impedance headphone amps and other audio systems where a small low-voltage power amp is required. Small high-impedance monitor speakers can also be driven. If using a power amp chip, such as an LM380 with a standard 8Ω speaker, an additional high-current 'odd-voltage' power rail is needed. By using an 80Ω speaker, the 50mA current consumption from standard op amp ±12V power rails can usually be accommodated, avoiding this power supply issue. The output power is 600mW.

For lower impedances, such as 8-32Ω, use lower voltage rails from ±9V to ±12V and use the higher current transistors BD435/6. With these low-voltage rails, high-gain, low-V_{ce} transistors can be also be employed in the earlier stages, such as BC549C and BC559C. TR3 was upgraded to an MPSA63 Darlington giving the least distortion. (Note this device has to be fitted to the PCB rotated by 180°). TR9 and T10 were upgraded to higher-current (BC327/37) devices to increase the drive to the output transistors. The I_q is increased to 54mA and the VAS current to 9mA. Using ±12V you get 1.4W$_{rms}$ into 32Ω, or 2.13W into 15Ω. A lot of component value changes were needed (see Fig.42. and parts list), giving an indication of the work required to optimise the circuit for a particular application. With these 'slow' power transistors the distortion is a little higher at 10kHz (see Fig.43), but much less than standard power-amp chips. The completed board is shown in Fig.44.

Preliminary testing

A dual power supply with a current limit is needed. Preferably, if there is

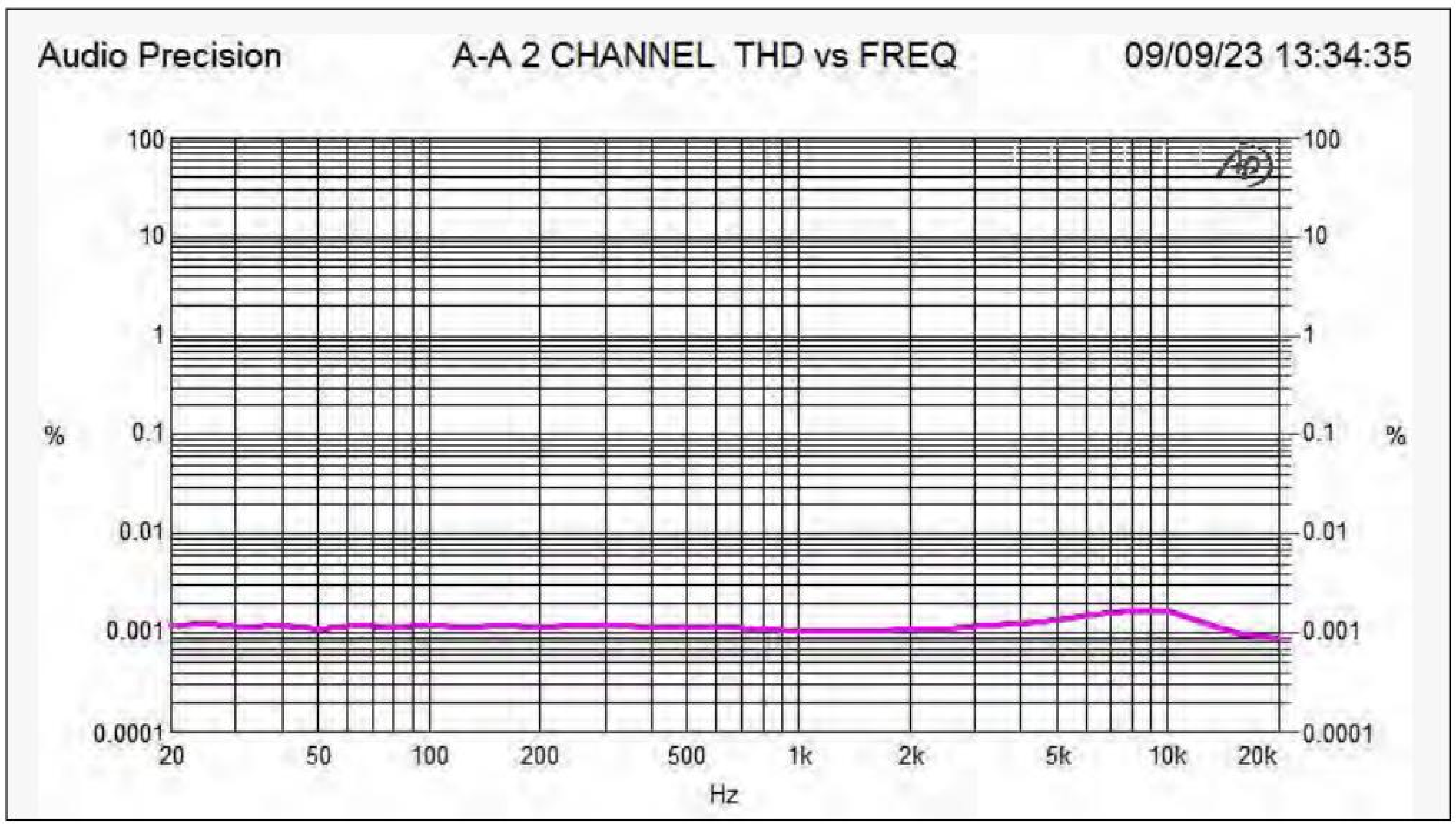
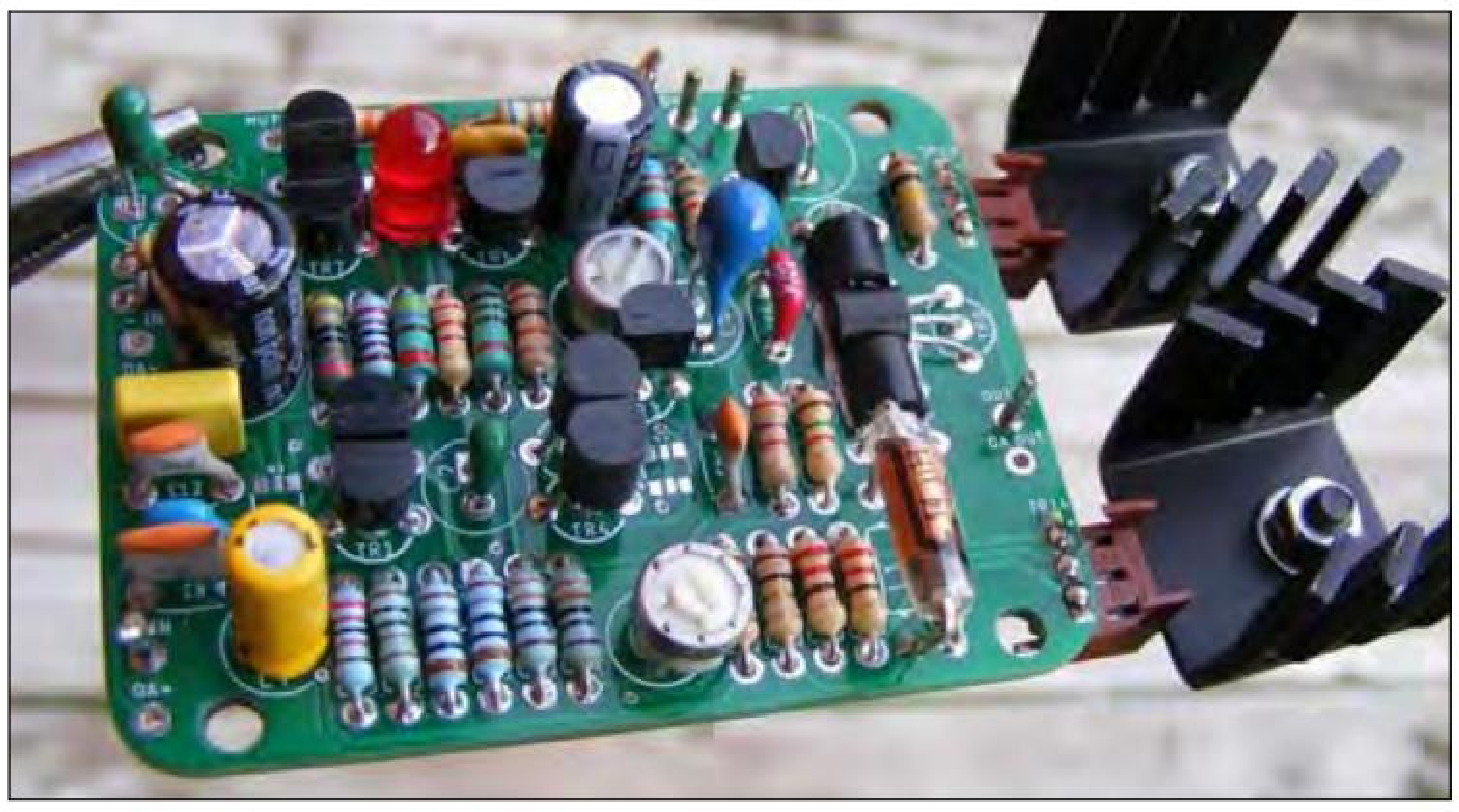


Fig.43. Distortion curve for *Discrete Audio Op* amp low-impedance headphone driver – load 33Ω, 2W resistor, ±12V supply.



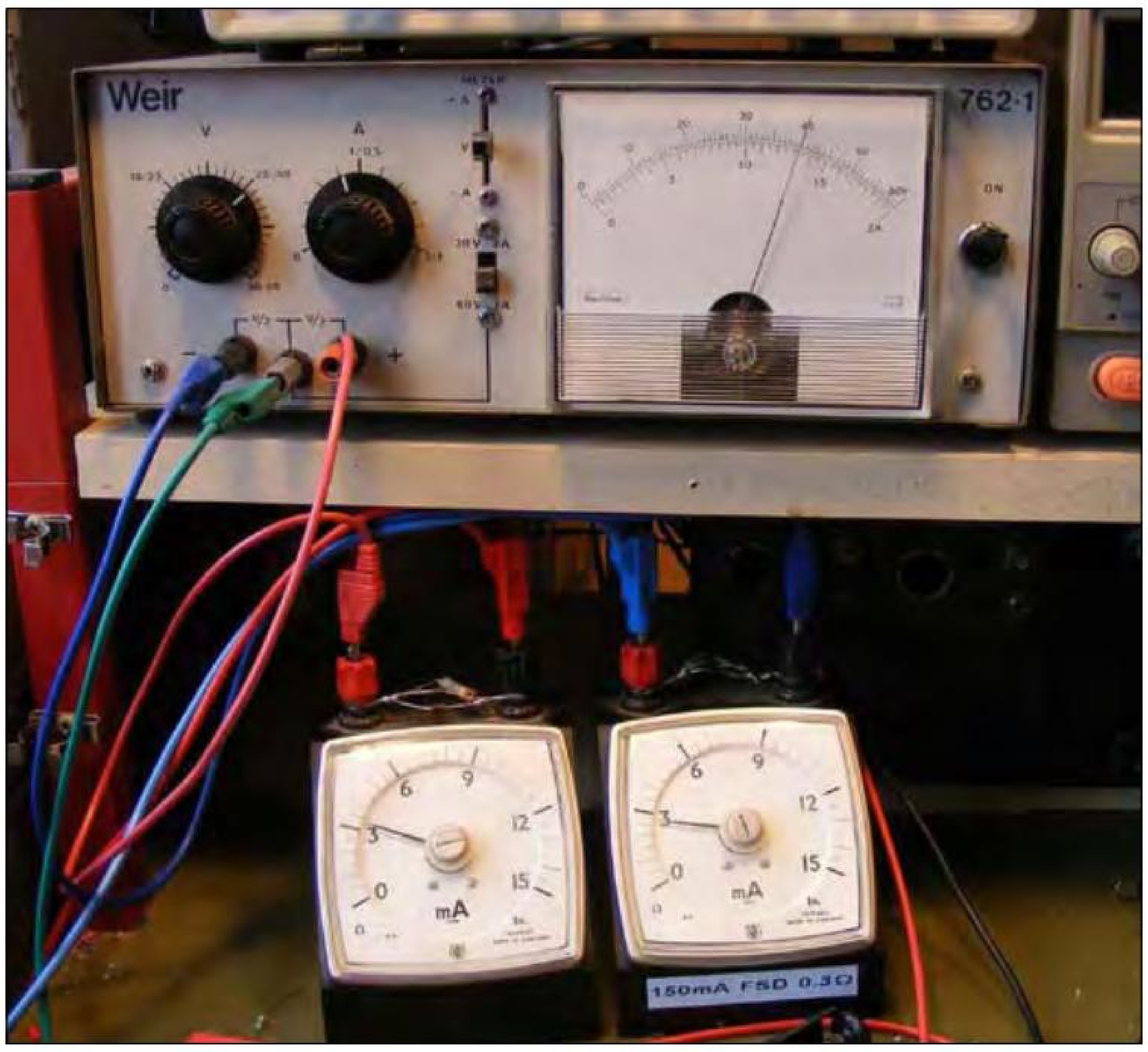


Fig.44. (above) Low-impedance version of the discrete op amp – this uses the MPSA63 Darlington for TR3; notice reverse orientation of the device.

Fig.45. (right) A good power supply set up using cheap radio rally equipment. A Weir 762.1 dual-rail power supply is well-worth seeking out for audio work. Old fashioned ex-college 150mA moving-coil ammeters complete the set-up. You can hear them hit their end-stops if the current jumps!

overcurrent on one rail it should shut off the other. It is also desirable to have current meters on each output. My power supply test set-up is shown in Fig.45. To start with, set the PSU to a low voltage, say ±9V. The current limit should also be set at around 200mA.

Before turning on, put the offset preset PR1 to its central position and the quiescent current preset PR2 to minimum current (maximum resistance, fully clockwise) and check if the power supply is connected the right way.

Now for the DC conditions check – do *not* connect a load at this stage, since if there's a fault it can provide a low-resistance current path to ground, aiding possible destruction. In directly coupled circuits such as this, just one transistor wired up wrong or a PNP inserted instead of an NPN, can cause it to latch to a power rail and destructive currents to flow. Switch on at a low voltage. The LED should light up and the current drawn should be between 10 and 18mA, and equal on both rails. It's then safe to slowly ramp up the supply voltage. If the current suddenly jumps that is usually an indication of oscillation. The LED will extinguish if this or overloading occurs. The next stage is to check the output offset voltage is below ±0.2V.

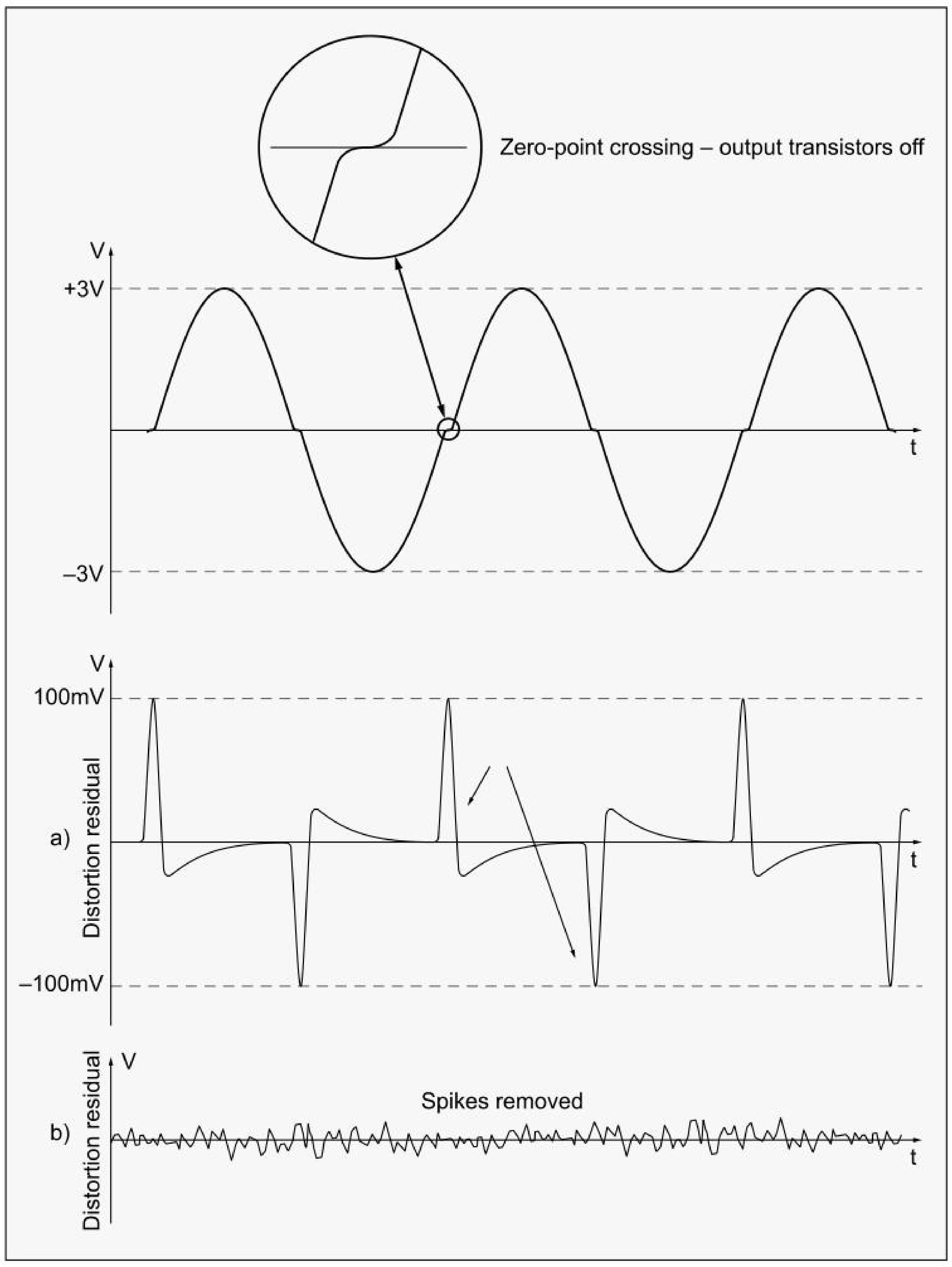


Fig.46. Setting *I*q: a) Bad crossover spikes, b) Clean residual.

Now it's time for AC testing. Use a 1kHz sinewave and oscilloscope. Check it clips symmetrically and there is no oscillation. Look for ringing and overshoot with a square wave. Then try it with a 620Ω load resistor. This all sounds like a lot, but it's just standard industry testing for any audio amplifier development. Next, set the offset preset (PR1, if fitted) and make sure the DC output is tweaked down to within a few mV either way. Finally, using PR2 set the quiescent current to 70mV across the emitter resistors, R11 and R12. If all is well, increase drive up to clipping at full voltage with a suitable load resistor.

Subtle testing

Distortion

For distortion testing, a load resistor is required. Low levels of distortion are very difficult to measure without specialist instruments. I used to use a John Linsley-Hood notch filter and thermistor-controlled oscillator, but this could only measure down to 0.02% THD. I later upgraded to a second-hand Audio Precision SY-2712 from Stuarts of Reading which produces the curves shown here: excellent hardware, awful software. High distortion is usually caused by instability, excessive loading or insufficient quiescent current. Looking at the distortion residual (that is what's left after filtering out the fundamental sinewave) can show the optimum quiescent current setting. The crossover distortion is revealed by characteristic spikes, as shown in Fig.46. Adjust the preset until they just disappear.

Noise

The way I test noise level is to set the gain of the op amp to 1000x and put it in a metal box powered by two PP3 batteries. An input load resistor reflecting the source is a good idea, enabling the LTP transistors (TR1 and TR2) to be selected and the current adjusted using R5. The set-up can then be tweaked for minimum noise. I have a 470mH Toko 10RBcoil and 300Ω resistor in series to represent a moving-magnet phono pick-up. The output of the op amp is connected to a scope via a BNC connector.

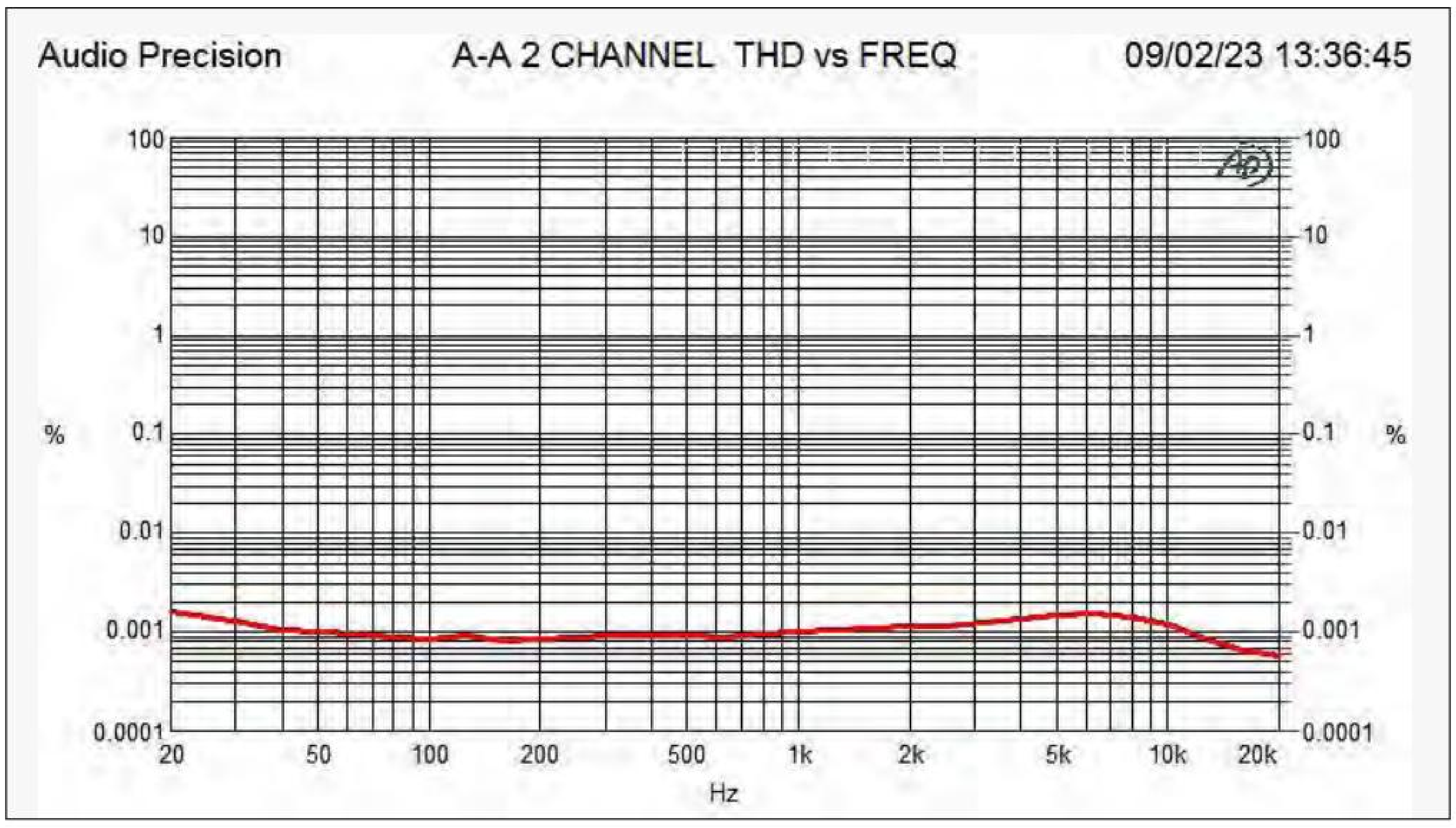


Fig.47. Distortion curve of 2N5564 JFET low-power version: load 600Ω, 6$V_{pk\text{-}pk}$ output.

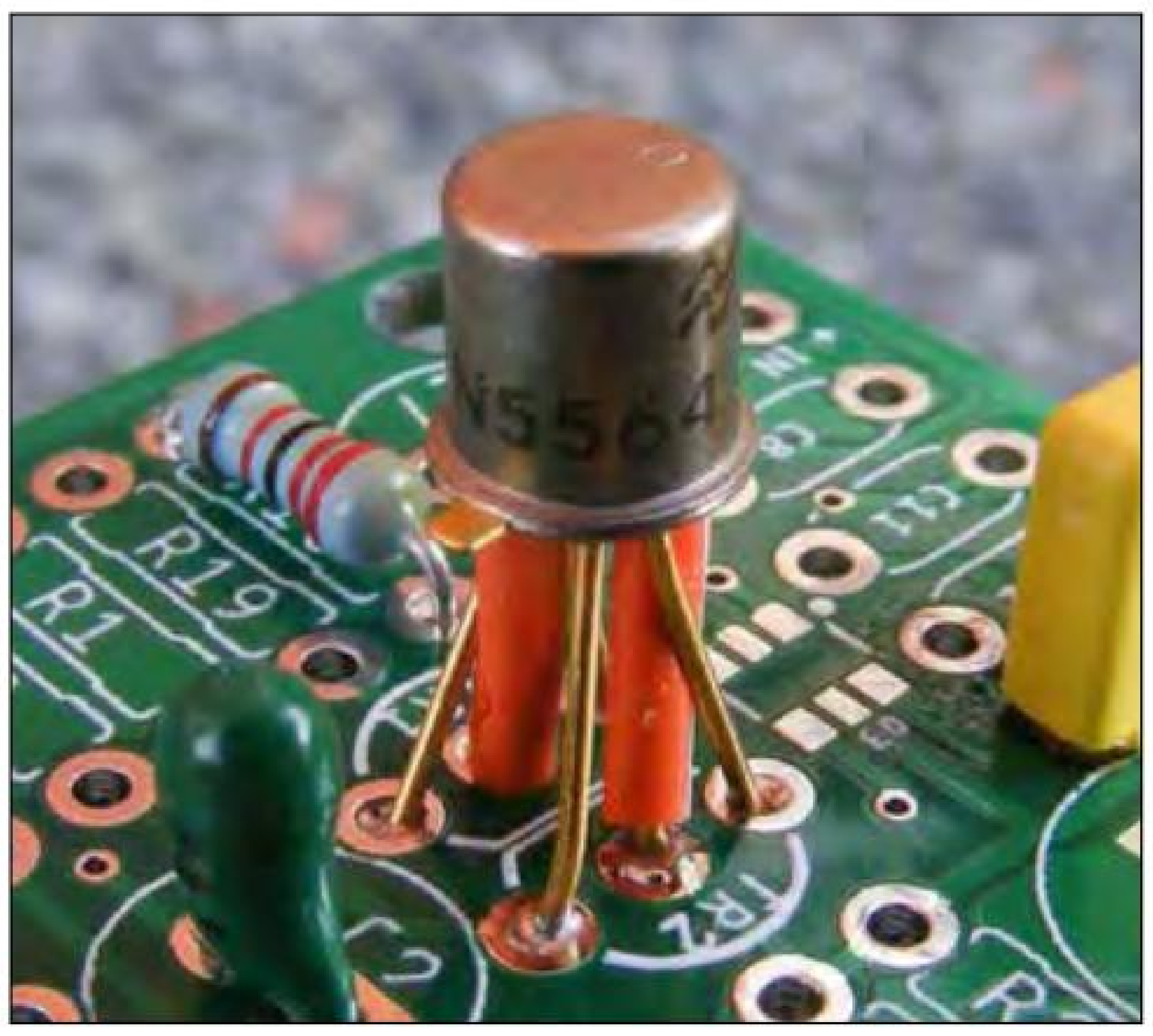


Fig.48. Dual JFET op amp using the 2N5564 in an unusual 6-pin TO18-sized package, called a TO71. The gate pins have to be crossed over and note the orange sleeving.

More transistor options

JFET op amp

I only have two leaded dual JFETs in my *AO Shop* stock, the 2N5564 and the E402. So I thought it was worth trying those first in the long-tailed pair. The E402 had low transconductance so I thought it best to keep selling those for Moog synthesiser oscillators. The cost of discrete dual JFETs from distributors, such as the Hi-Fi 2SK389, is shocking. Possibly the best input devices in the world are the InterFET devices IF3601 (£22) and the dual IF3602 (£60) from Mouser. If I was designing a hydrophone pre-amp for the military they might be a good choice.

Increasing the drain current in JFETs increases the transconductance, but unlike bipolar transistors, there's no increase in bias current to worry about. Also, the noise voltage in proportion to current decreases up until I_{dss} (the saturation current) is reached. Thus, the operating current (I_d) through JFETs may be quite high: 1 to 5mA per device.

If you want a cheap JFET for experimenting, the BF244A is a good choice because it has a centre gate pin and is inserted in the PCB with the same orientation as a BC546 (see Fig.25 last month). Remember to link out the emitter resistors R1 and R2. I tried increasing the current to 2mA by reducing R5 to 220Ω and correspondingly reducing the current mirror resistors R3 and R4 by half. This made no difference, but I was surprised to see that with the current mirror resistors linked out, distortion was much worse. Interesting – I think the resistors linearise the mirror. Using a 2N5564 dual JFET at ±15V, the distortion is a bit higher than the bipolar version, but at the full rail voltage of ±25V it was better, as shown in Fig.47. The offset was very low without trimming, around 3.4mV. A photo of the board is shown in Fig.48. With random BF244A devices the offset was high in the order of 0.5V, although it was easy to select matched devices using sockets.

Toshiba do a dual SMT JFET, the 2SK2145-Y, which is cheap (50p from Mouser). It's got a strange pin-out where the sources are joined together. The 2N5564 dual JFETs (pin outs shown in Fig.49) are also available from Digikey and Keytronics (in the UK).

The SOI-23-6 adapter board was designed by Rex Harper at **www.QRPme.com** – a US site. It's also available from Telford and District Amateur Radio Society (TADAR) and the *AO Shop*. This is shown in Fig.50. Stop press. I've just designed a drop-in mini PCB created by Mike Grindle which I'll put at the end of the article. I've only just received them, see Fig.56 for a photo.

John Linsley-Hood

The late John Linsley-Hood, a long time writer for *PE*, had some interesting ideas, which I just had to try. He used a VN1210M MOSFET for the VAS stage (TR3) in his popular power amps (*Electronics Today International*, July 1984). This provides a minimal load on the current mirror output (TR4's collector), maximising the open-loop gain. It should give the performance of using a VAS stage with an input buffer. The transconductance of MOSFETs is also adequate. The high noise level of MOSFETs is not a problem, since it is in the second stage. When I substituted a ZVP2106A P-channel MOSFET for TR3 the distortion at 10kHz was doubled compared to the BC556B, A ferrite bead on the gate connection was also needed for stability. Sadly, at this stage I wouldn't recommend MOSFETs based on this experiment, but I will try some other types.

Linsley-Hood also used small-signal monolithic Darlington transistors (MPSA13/63) in his *Liniac*, an early dis-

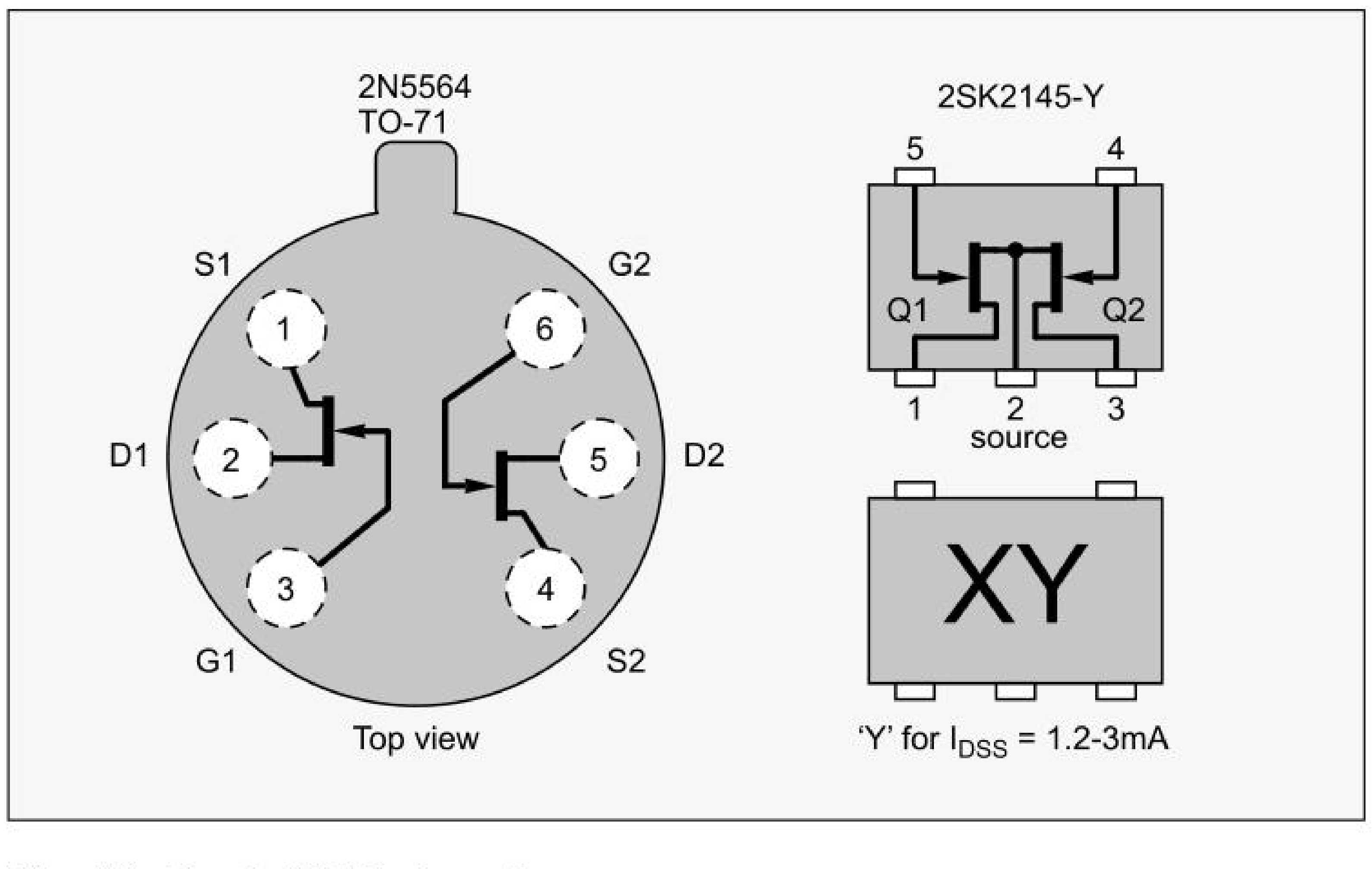


Fig.49. Dual JFET pinouts

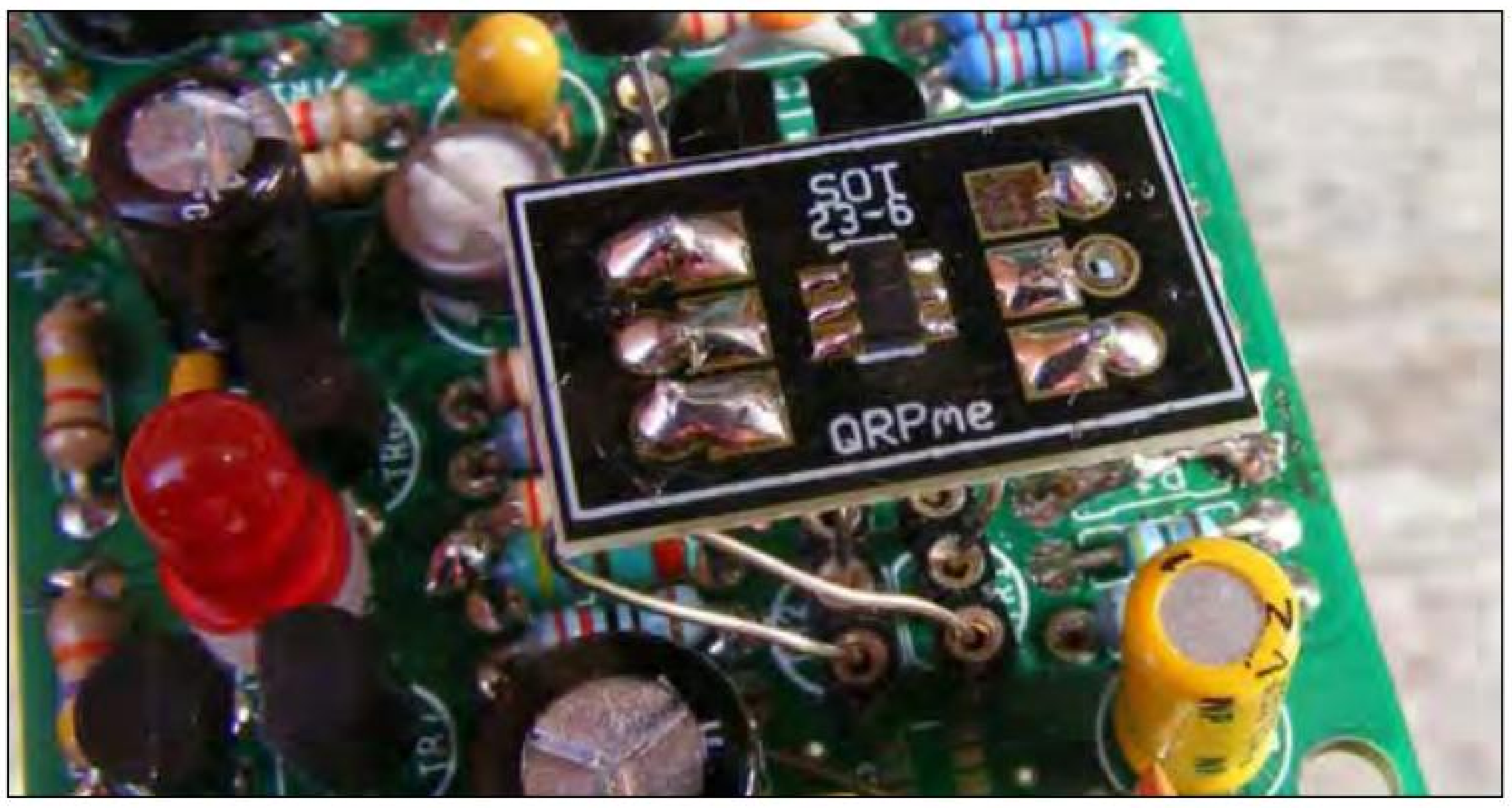


Fig.50. An adaptor PCB is needed to mount the SMT 2SK2145 JFET on the board. Note the gates are the two pins on the left side of the 5-pin pack.

crete op amp described in *Wireless World*, September 1971. I substituted an MPSA63 PNP Darlington for TR3 and was surprised at the improvement, giving the lowest distortion of all devices tried. I think the H_{fe} of 5000 and the extra V_{be} voltage drop across the current mirror output accounts for this. The voltage rating of this device is only 30V, thus limiting the power rails to an absolute maximum of ±15V, but that is fine for the low-impedance version of the op amp. Two BC556B transistors connected in a Darlington configuration produced slightly better results without this voltage limitation.

Optimum source impedance (OSI)

The tail current for the LTP pair (TR1 and TR2) can be changed by adjusting one resistor – R5. Of course, the current is divided in two between the devices. If the tail current is increased the current mirror matching resistors (R3,R4) must be reduced, since there is only 0.7V operating voltage available for this stage.

Table 2 shows a a list of noise voltages, optimum currents and source impedances for popular low-noise input transistors. Some of these figures are from Baxandall's chapter eight in the *Microphone Engineering Handbook* edited by Michael Gayford (Focal Press 1994).

Output transistors

The BD139/40 transistors can be usefully upgraded. Into 100Ω the BD139/40 gave 0.004% THD. I made some boards, shown in Fig.51 with Molex 0.1-inch sockets which provide excellent transistor holders for substitutions and testing. The 2SD669A and 2SB649A (PNP) complementary pair from UTC are a superior replacement with equal values of F_t of 140MHz and a higher voltage of 160V. However, their maximum current is limited to 1.5A. Unlike most audiophile drop-in replacements, I was gratified to see the distortion was slightly better at 0.0015% into 180Ω. If larger powers, say over $2W_{rms}$ are needed for lower impedances (<50Ω), you have to use higher-current devices with heatsinks. The MJE253G (PNP) and MJE243G from OnSemi are also good, with 40MHz 15W ratings. The MJE182/172 were used in Samuel Groner's op amp (rated 3A 80V 50MHz). None of these transistors needed C5 for stability.

Generally, you have to change from fast planar to traditional power epitaxial-base transistors to get even higher power and current ratings. These devices can have an F_t as low as 3MHz, such as the TIP31A/32A and BD435/6. In theory, this means the high-frequency distortion is going to be higher and the compensation arrangements will have to be redone. In practice, this did not come to pass and surprisingly they worked fine, giving 0.002% THD into 180Ω.

This complex op amp topology gives excellent results with average transistors because all the conditions are held rigidly by high feedback, current sinks and voltage references. Simpler audio amplifiers show up the differences more. Profusion sent me some samples of triple-diffused Sanken 2SA1725 and 2SC4511 30W 20MHz devices (although H_{fe} was low at around 50). These would work very well using the op amp as a small Hi-Fi power amp. For example, driving a tweeter in an active speaker. Note the metal tab faces outwards or downwards for the bigger TO220 devices, the opposite for the smaller TO126 cases. See Fig.52. Table 3 details some output transistor options.

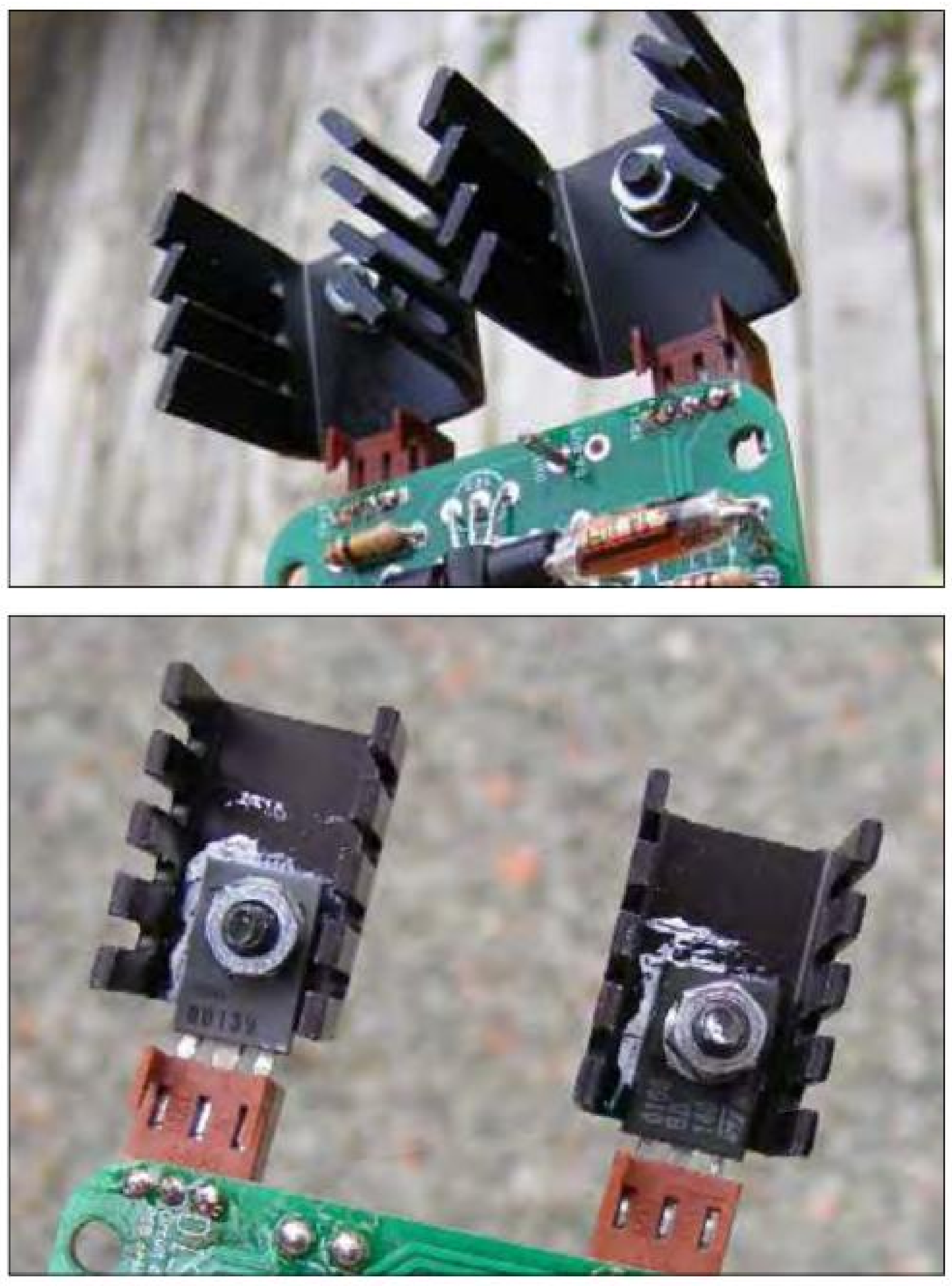


Fig.51. Right angle Molex sockets make good power transistor sockets for testing.

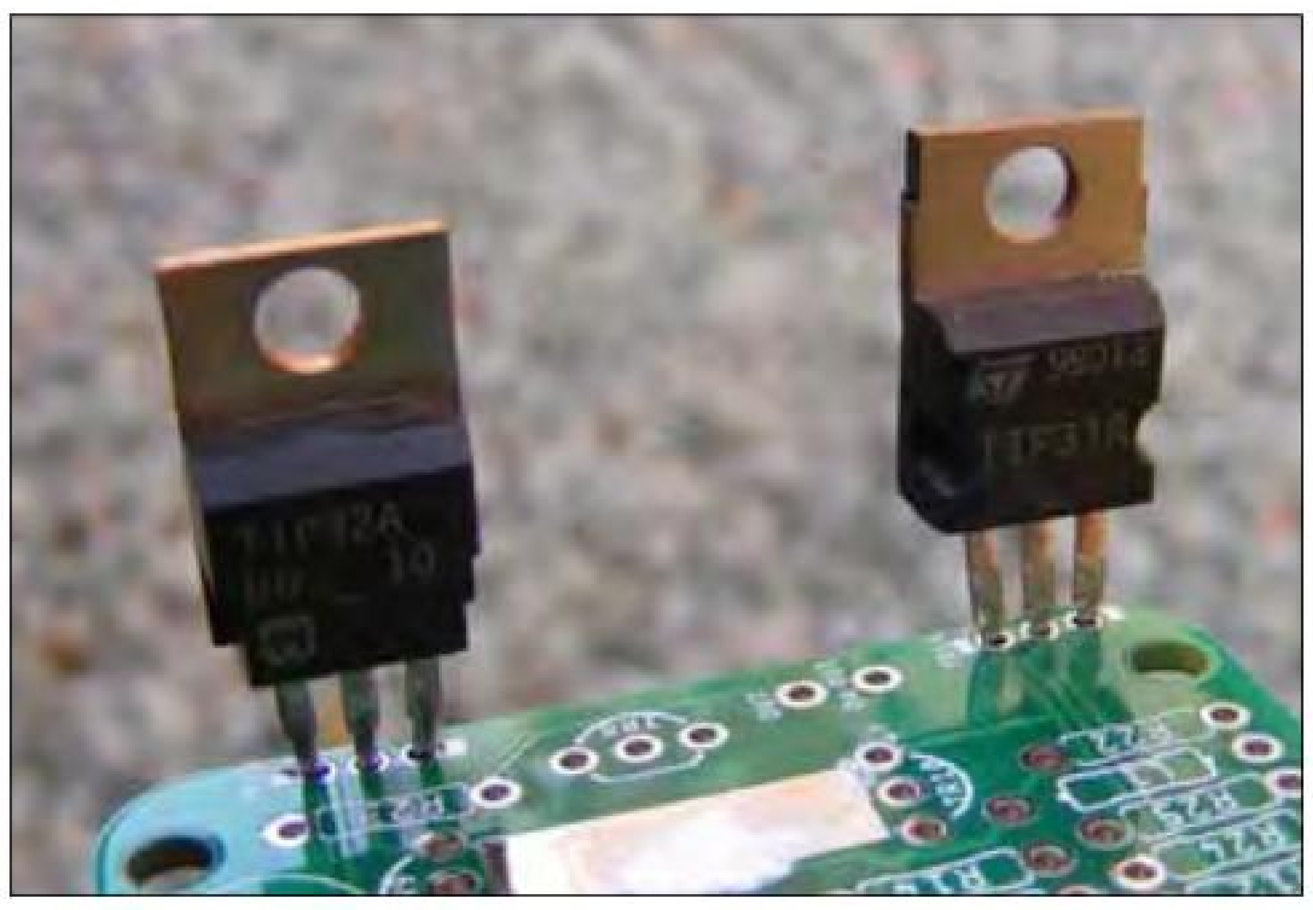


Fig.52. Orientation of power transistors TR13 and TR14 using TO220 devices.

Table 2. Low-noise input transistors

Device	**Polarity**	**nV/√Hz***	**OSI**	**I_c**	**Notes and noise factor**
NE5534A	NPN	4	8kΩ	0.13mA	IC op amp reference
BC549C	NPN		5.5kΩ	0.1mA	1-3dB specified
BC559C	PNP		5kΩ	0.1mA	1-3dB specified
BC550C	NPN		5kΩ	0.1mA	2-4dB specified
BC560*	PNP		5kΩ	0.1mA	2-4dB specified
BC546	NPN		2kΩ	1mA	Unspecified ~4dB
BC556	PNP		2kΩ	1mA	Unspecified ~4dB
BC143	PNP		260 Ω	1mA	0.65dB
2SC2240**	NPN	1	1kΩ	1mA	0.5dB
2SA970A**	PNP	0.9	1kΩ	1mA	0.5dB
2SC2362	NPN		10kΩ	0.1mA	1dB
2N4401	NPN		420Ω	1mA	0.61dB
2N4403	PNP		473Ω	1mA	0.5dB
2N5564	N-chan	3	>10kΩ	2mA	1dB JFET dual
2SK2145-Y	N-chan		>50kΩ	1mA	1dB JFET dual
J230	N-chan	2	>100k	0.5mA	1dB JFET
HN3C51F**	NPN		10kΩ	0.1mA	1dB dual NPN 120V
HN3A51F**	PNP		10kΩ	0.1mA	1dB dual PNP 120V

*At 1kHz

**Obsolete – sadly, the best audio transistors are disappearing fast.

Other applications

There are almost as many applications for discrete op amps as for the integrated variety. But we'll have to leave off here with just a few ideas.

Phono amplifier

Single op amp phono amplifiers are very demanding, needing very low noise and high gain. A rather odd requirement is that they also need to drive an RIAA feedback network that often has an impedance down to 220Ω at high frequencies. High headroom is also needed to cope with sudden scratches. If the pick-up is a moving-magnet cartridge then an optimum source impedance is needed that is fairly high, in the region of 3kΩ to 9kΩ. For this, standard BC549C input transistors running at 0.1mA to 0.2mA work well. The NE5534 op amp, which was designed for moving-magnet cartridges, runs its input transistors at 0.19mA. Conversely, moving-coil cartridges are very low impedance, sometimes only 22Ω, and low base-spreading R_{bb} resistance devices such as the 2SB737 and BFW16 are used at high currents. A suitable

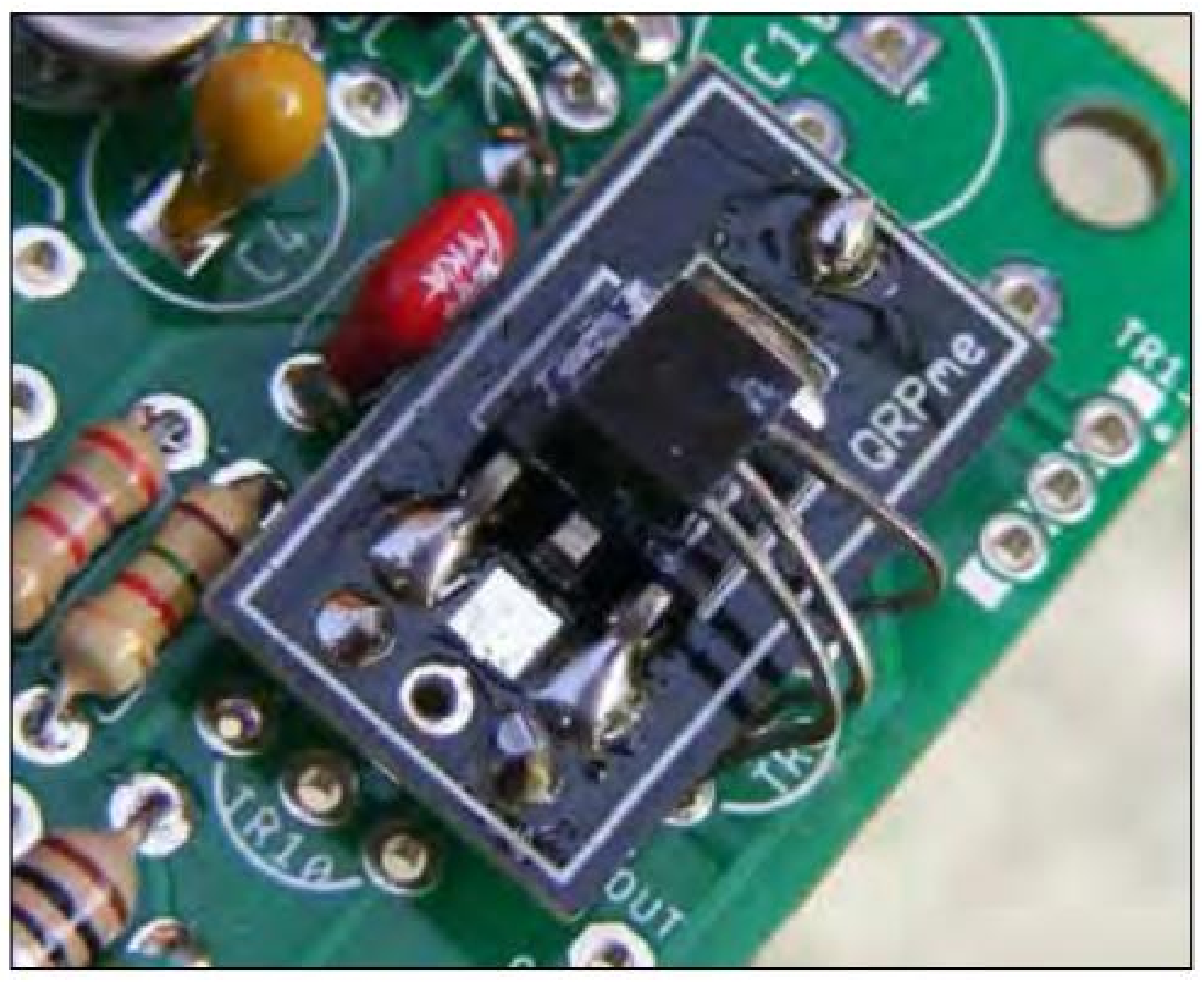


Fig.53. Fitting SMT output transistors using the SMT adaptors. Note the bent over TR8 for temperature sensing. I used a ZTX651 here for its flat pack. This made an excellent 80Ω ±12V headphone amp.

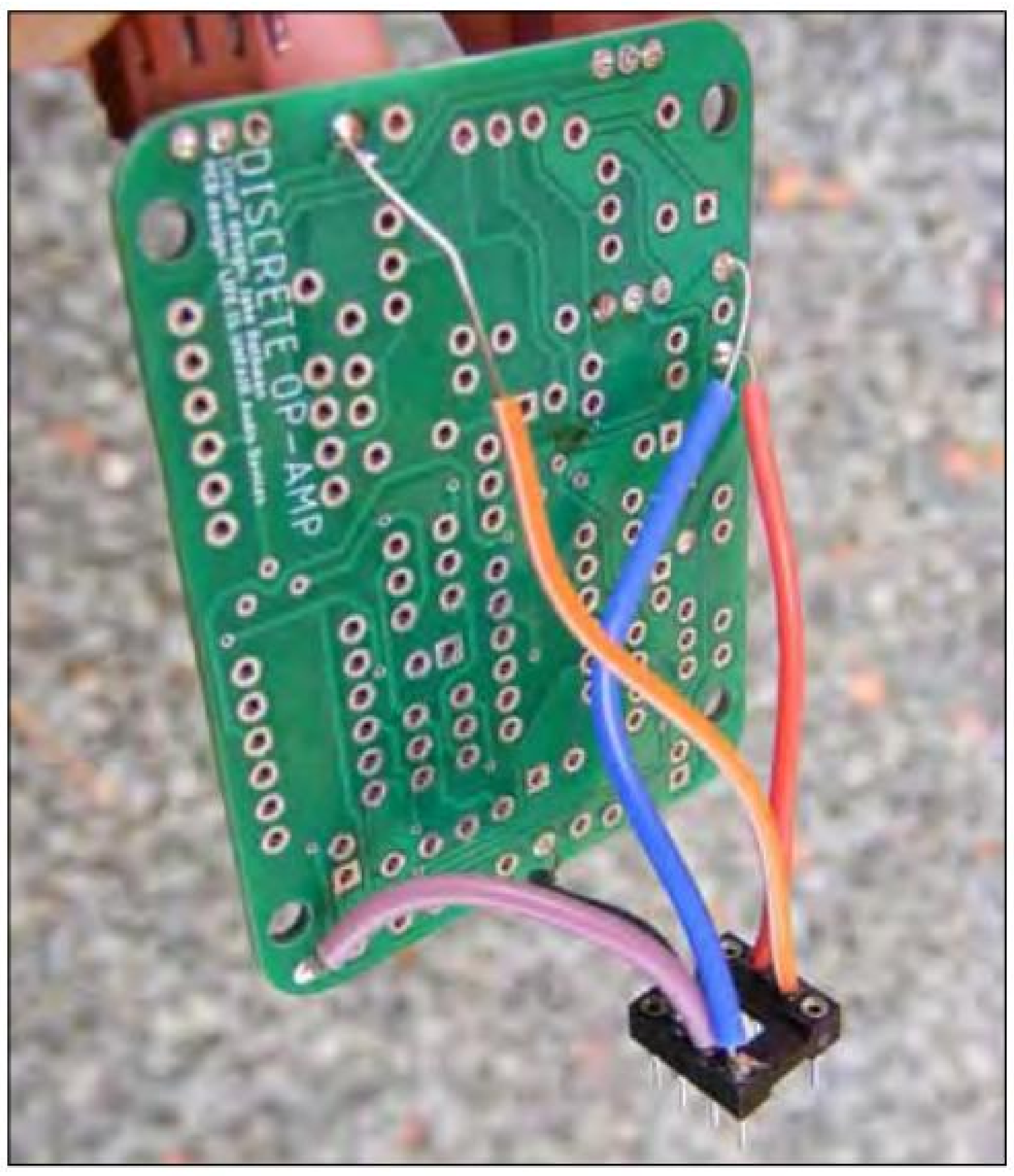


Fig.55. (left) Basic *Discrete Audio Op Amp* set up for drop-in replacement of an integrated op amp. Note R20, R21 and C9 feedback, and the input and output components are left out. The op amp connections are 25 swg tinned copper wire soldered directly into an 8-pin DIL turned-pin socket which plugs into a chip socket to replace an IC op amp. Note the earth pin on the PCB will have to go to the 0V on the IC PCB. There's normally no earth pin on the chip socket.

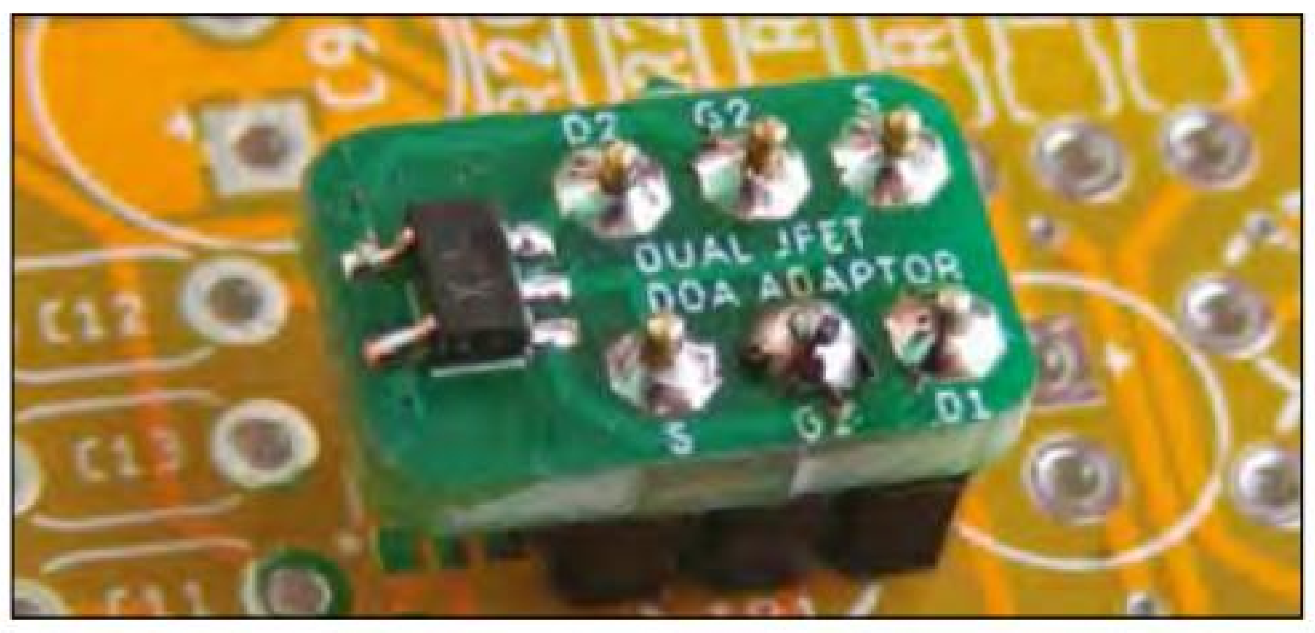


Fig.56. Stop press. There will be a dedicated dual JFET adaptor board for the 2SK2145. (It will be supplied with the main PCB.)

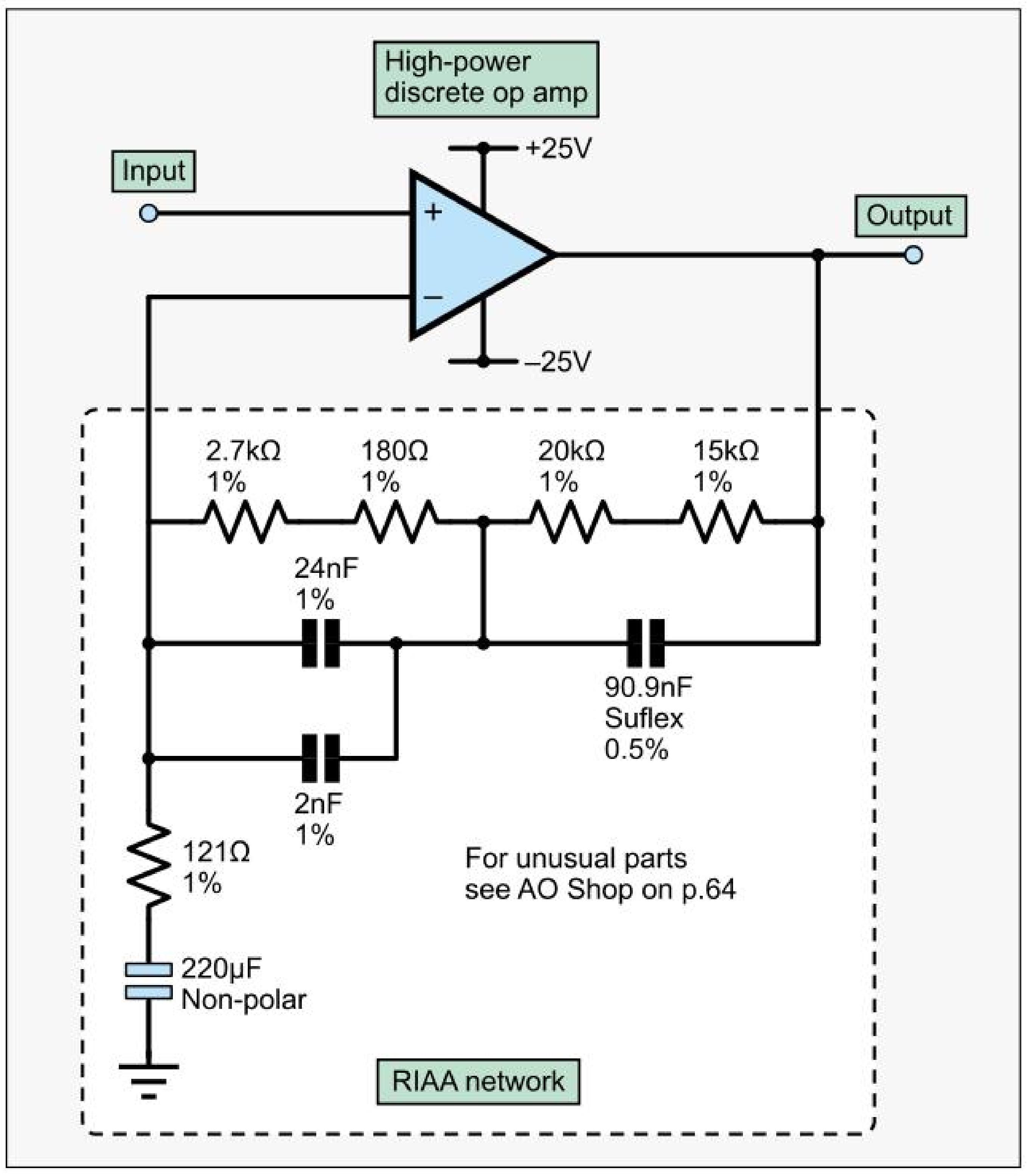


Fig.54. Suitable RIAA feedback network for the *Discrete Audio Op Amp.*

low-impedance equalisation network is shown in Fig.54.

50Ω signal generator booster

Many audio signal generators don't have high output swing. My Rapid Pintek FG-32 is limited to ±10V. The solution is to have an add-on amplifier with a gain of 3, running on ±25V. A signal generator is expected to have a 50Ω output impedance and be able to drive 50Ω. An amplifier with a capability to drive 100Ω is needed, via a series resistor of 50Ω 2W. The design would have to be tweaked to have a very high maximum frequency.

48V single-rail working

As with all dual-rail op amps, this circuit can be biased to half-rail to obtain symmetrical output swing on a single power rail. This gives us the tantalising prospect of designing systems using the audio/telephone standard of +48V rail. This makes a single-rail microphone amplifier with phantom power (which is +48V) a possibility. Normally, microphone amplifiers need three rails, +17V, –17V and +48V. A single-rail design reduces power supply complexity and cost as a result. Note that polarised capacitors C7, C9 and C10 will have to be reversed.

Going straight

During audio product development it is useful to have a discrete op amp that can plug into a standard 8-pin DIL socket to substitute for a chip. In conjunction with the universal op amp board (*Audio Out*, December 2022) one can easily verify a system before committing to a final PCB. An 'umbilical cord' can be made to an 8-pin DIL plug as shown in Fig.55. The leads are connected to the op amp pins under the board and the audio input/output components are omitted. You have to be careful to keep the input leads short to avoid pick-up and instability.

All this goes to show the huge versatility and diversity of tweaks that can be applied to a discrete operational amplifier. I hope you come up with some unique designs and applications of your own.

Table 3. Output transistor options

TR13 (PNP)	TR14 (NPN)	C5	V_{ce}	I_c	Notes
BC327	BC337	NO	45V	600mA	Higher current than BC546/56, driver.
BD136	BD135	NO	45V	1.5A	Low-voltage (±12V) 80Ω
BD140	BD139	YES	80V	1.5A	High-voltage (±30V max)
BD436	BD435	NO	45V	7A	Low-voltage, high-current 7A 32Ω
TIP32A	TIP31A	NO	60V	6A	Makes small power amp, TO220 case
ZTX751	ZTX651	NO	60V	2A	Small, fits well on thermal pad, driver
MJE253G	MJE243G	NO	100V	4A	High-frequency small power amp
2SB649AL	2SD669AL	NO	160V	1.5A	Higher quality BD139/40
2SA1725	2SC4511	NO	80V	6A	High-frequency power amp TO220
2SA2039-TL*	2SC5706-TL*	YES	50V	5A	SMT SOT-223 outline. 50V V_{ce}, so limit rails to ±22V max.

* I wanted to test these devices for a possible SMT discrete op amp. I was disappointed to find they initially gave more distortion (0.01% THD into low impedance 100Ω loads) compared to the others in the CFP output. The 5A maximum current and H_{fe} of 300 suggested they should have been better. It turned out the problem was very high-frequency oscillation. Their very high 300MHz F_t was so good it may have caused the problem. It was fixed by making C5 270pF and adding an additional capacitor of 150pF across the base-collector junction of TR9. A Zobel network, connected to ground from the op amp output of 15Ω and 47nF, was also required. Using these transistors in the straightforward emitter-follower output (TR9 and TR10) gave excellent results, so a good SMT op amp is possible. A prototype taking shape is shown in Fig.53.

AO*Shop*

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors	
NKT214F, OC57, OC59, 2N1377, 2N525	**£1.00**
Low-noise PNP transistors	
GET106	**£2.50**
Small power PNP transistors	
AC153, AC153K, AC188, AC188K	**£1.50**
Small power NPN transistors	
AC176, AC176K, AC187K, AC141K	**£2.00**
High-voltage PNP transistors	
OC77, CV7001	**£1.50**
TO3 PNP power transistors	
OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	**£2.00**
AD140	**£3.50**
AD149, AD161/2 matched pair	**£5.00**
RF PNP transistors	
OC41, OC42, 2SA12, 2SA53,AF124, AF178, GET872A	**£1.50**
NPN transistors	
OC139, OC140, ASY73	**£2.00**
Diodes	
CV7049 (OA10), CG92 (OA91)	**£0.50**

Si semiconductors

Diodes	
ZC5800 RF Schottky	**£0.20**
Low-noise silicon transistors	
BFW16A, 2SC3071, 2SC3068, 2SA1016K, 2SC2362K, 2SA970BL	**£1.50**
2SC2204, 2SD655, BC550C	**£0.50**
ZTX651	**£0.30**
ZTX751	**£0.50**
RF transistors (suitable for Theremin)	
BF199	**£0.50**
Audio power MOSFETs	
Exicon 10N20, 10P20	**£6.50**
Hitachi 2SJ99, 2SK343	**£3.50**
Hitachi 2SJ56, 2SK176	**£8.50**
JFETs	
BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176, J201	**£1.00**
J175, J176, J112, J111, 2N3820, 2N5467, BF244, 2N5460, J230	**£0.60**
Small power output/driver transistors	
2SB649A, D669A, 2SA1208, 2SC2910, MJE253G, MJE243G, 2SA1725, 2SC4511	**£1.20**
BD139,BD140, BD135, BD156, BD435, BD436, MPSA63, BCV46	**£0.50**
MOSFETs	
ZVP2106A	**£0.30**
Dual-gate 3SK45, BFS28	**£1.50**
Metal-cased transistors	
BC143	**£0.35**
2N1711	**£0.50**
BCY71	**£0.30**
BC109C	**£0.60**
Amplifiers	
LM318 high-speed op amp	**£0.35**
µA709 metal-cased op amp	**£2.00**
5534H metal-cased op amp	**£3.00**
LM384, TDA2030A, TDA2050V	**£1.50**
TAA435 (Mullard power amp driver)	**£1.20**

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That/dbx 2180 VCA/VCF	**£6.00**
CA3080 VCA/VCF (vocoder)	**£2.80**
CA3280 VCA/VCF	**£4.00**
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PT2399 echo/delay	**£1.50**

Dual transistors

2N2639, 2N2223, 2N2910 (NPN)	**£4.00**
E401 (JFET Moog)	**£4.00**
2SK2145-Y dual JFET	**£0.80**
2N5564 JFET	**£8.00**
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DMMT3904/6, HN1A01F, HN1C01F	**£0.50**

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Volt PE165 6.5-inch woofer (each)	**£85**
Morel MDT29 tweeter (each)	**£25**
Kit *pair* of PE165/MDT29 plus Volt crossover parts and PCBs	**£299**
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Vifa 19mm BC20SC15-04 tweeter (each)	**£15**
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1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	**£5.85**
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Vifa TC26 1-inch tweeter (each)	**£10**
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EMI 10x6-inch, 30Ω Alnico	**£7**
64mm 64Ω neodymium	**£1.20**
5x3-inch elliptical 50Ω or 80Ω Alnico	**£3.50**
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Capacitors

Note '10/63' denotes '10µF 63V'.

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5.6/63, 8.2/63, 10/63	**£2.00**
Mullard 'Mustard' C296 0.22/400	**£2.00**
Polycarbonate	
Axial 2.2/63 1%, 4.7/160, 6.8/63	**£1.00**
Radial	
6.8/160V, 10/63	**£2.00**
Reclaimed 22/63	**£2.00**
Polystyrene	
Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63, 24nF, 2nF	**£1.00**
RIFA 1% 100nF/100, Suflex 90.9nF 0.5%	**£2.00**
Suflex 2.5% 10nF/63 (rad. or ax.)	**£0.50**
Radiation resistant	
Siemens cellulose acetate MKL 2.2/25	**£0.80**
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10/25, 22/25, 100/10	**£0.50**
150/40, 470/40, 1000/40	**£1.00**
Tantalum – axial metal cased	
22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	**£2.00**
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	**£1.25**
4.7/50, 6.8/35, 10/25, 10/35, 22/15	**£1.00**
Axial moulded-case tantalum	
Kemet axial 6.8/10	**£0.30**
Kemet radial 33/10	**£0.40**
STC radial 100/20	**£1.50**
Tantalum bead	
22/50	**£1.00**
470/3	**£2.00**
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Wet tantalum	
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Castanet button 140/30, 470/3	**£3.20**
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Generic radial 100/16, 470/35, 100/ 63, 22/35, 4.7/35, 220/16	**£0.50**
Philips solid-aluminium (axial) 121/123	
47/16	**£1.00**
330/6.3	**£2.00**
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10/16	**£0.30**
Silvered mica (radial)	
1nF/500 1%	**£1.00**
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Eagle transformers	
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LT30 500mW output	**£3.50**
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Repanco	
T/T3 splitter transformer	**£4.00**
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Vigortronix 600Ω VTX-101-007	**£10**
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Vigortronix 600Ω VTX-101-3002	**£15**
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Bourns wire-wound trimmer 5kΩ 3059 JM panel-mount	**£2.00**
Thermistor RA53, R13	**£4.00**
A13	**£2.00**
Thermistor CZ1, CZ6	**£1.50**
Holco H2 2.2MΩ 1W, 1%	**£1.00**
Welwyn 1GΩ 2W	**£1.00**
5k Bourns 3321H cermet trimmer	**£0.50**

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Bourns 81	
25kΩ lin cermet	**£2.00**
25kΩ lin, 5kΩ lin conductive plastic	**£3.00**
Bourns 91	
10k dual-gang lin or log	**£10.00**
Plessey moulded-track	
5kΩ log with switch	**£3.00**
50kΩ A/log	**£3.00**
Mil 250kΩ lin dual	**£5.00**
Alpha	
16mm 4.7kΩ A/log	**£0.80**
220kΩ A/log	**£0.80**
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Allen Bradley J series/Honeywell	
10kΩ lin 1 million cycles	**£5.00**
Blore Edwards AB 45 dual 5kΩ A/log with switch	**£3.50**
Alps RK9 dual-gang 5kΩ RD law	**£4.00**
Alps 50k log tapped motorised stereo	**£5.00**
BI P260 500kΩ log conductive plastic 1 million cycles	**£2.00**
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	**£5.00**
Mil Spec hermetic 10Ω	**£8.00**

Miscellaneous

Theremin Clearance Sale!	
Elysian Theremin MIDI box	**£300**
PCBs	
Pocket Theremin (*EPE*, 1996)	**£2.00**
Elysian Theremin (*EPE*, 1996)	**£6**
Synth VCF, VCO (*EPE*, 2017)	**£3.00**
48V PSU (*EPE*, 2019)	**£3.00**
SMT dual transistor adapter	**£0.40**

Contact
Jake Rothman
The Old Rectory, Arlais Road,
Llandrindod Wells, Powys
LD1 5HE (visit by appointment)
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jrothman1962@gmail.com

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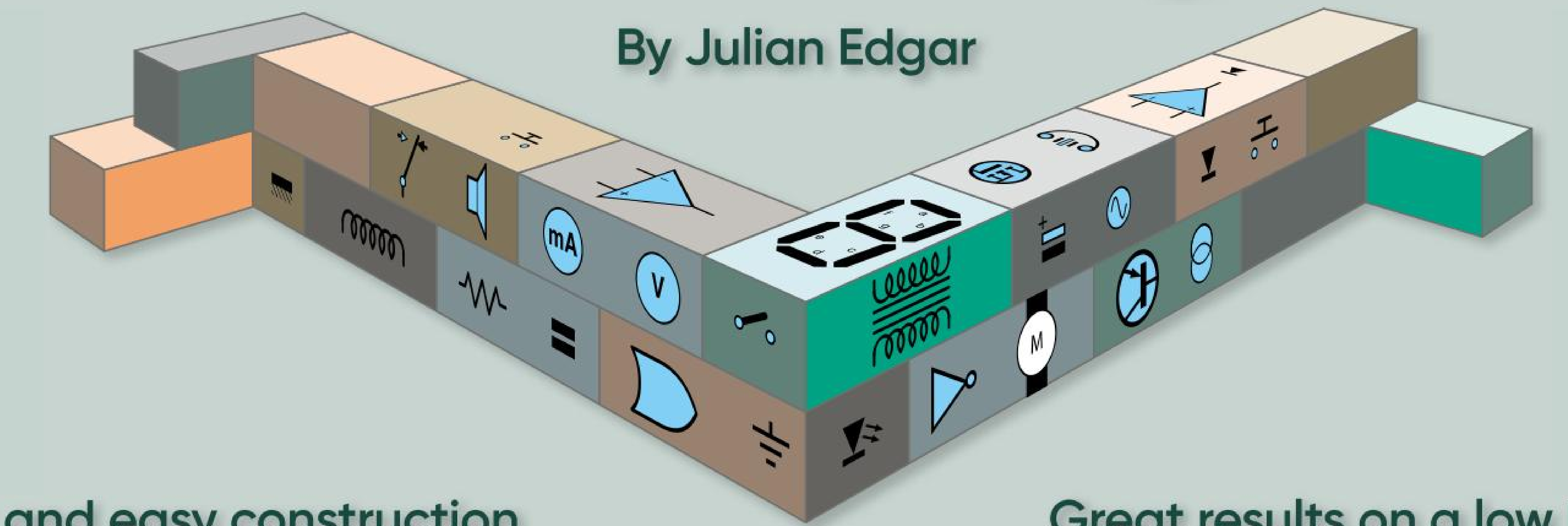
Electronic Building Blocks

By Julian Edgar



Quick and easy construction

Great results on a low budget

Long-distance Remote Control

Ideal for triggering outside lighting, this remote control features a mains power relay and can switch high loads. It can reliably operate in difficult conditions over a 300m range – and further than that when in direct line of sight.

This project came about because I couldn't find anything off the shelf that satisfied my requirements – not at a reasonable price, anyway. So, what did I want? I wanted to switch some powerful outside lights – but there was a problem. The lights are at the entrance gate of the block next door, where one day we will build a house. I wanted to be able to switch the lights from our existing house, and then in the future, from the new house. The obvious answer was to use a remote control – then the lights could be turned on and off from anywhere, now and in the future.

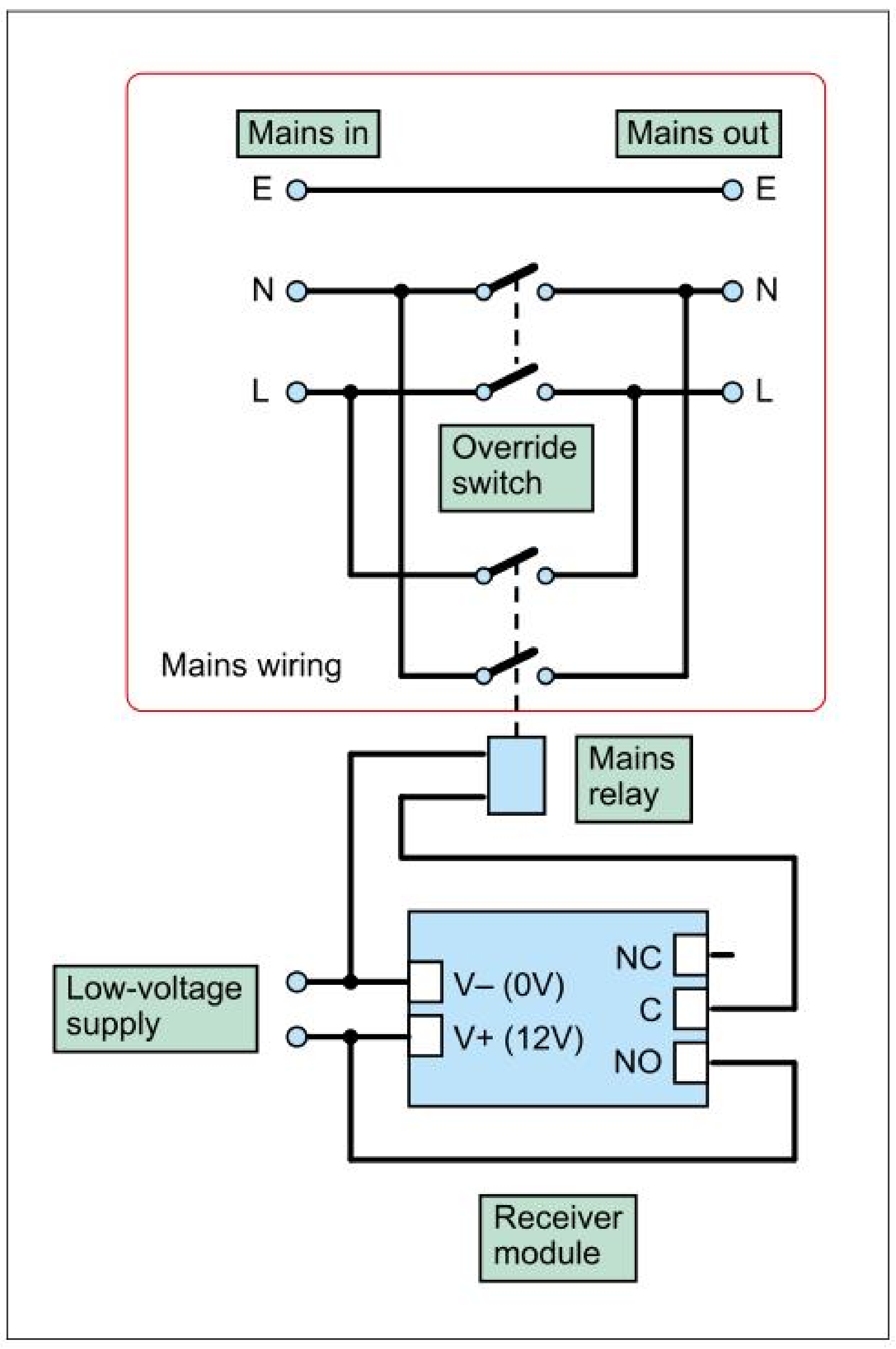


Fig.1. The remote-control receiver module (bottom) triggers a mains-rated relay (middle). An override switch (top) allows the output to be switched even if the remote control isn't working. Note that all the wiring in the upper box is mains wiring and must be suitably rated and insulated.

But the first problem was range. The remote control's receiver was to be mounted in a mains power meter box – that where's the power for the lights was being sourced. But that box is about 80m from our existing house, and about 100m from where the new house will go. And cheap remote controls typically don't work over anywhere near that range – especially when the receiver is located inside a metal box!

The second problem was switching the mains power. While many cheap remote-control modules claim to have mains-rated relays, the '10A at 240V' relay inscription doesn't mean much when the PCB tracks and terminals are completely inappropriate for such mains connections.

So, the answer was to assemble my own system – quite easy and, especially if you already have some parts like a mains power relay and box, cheap as well.

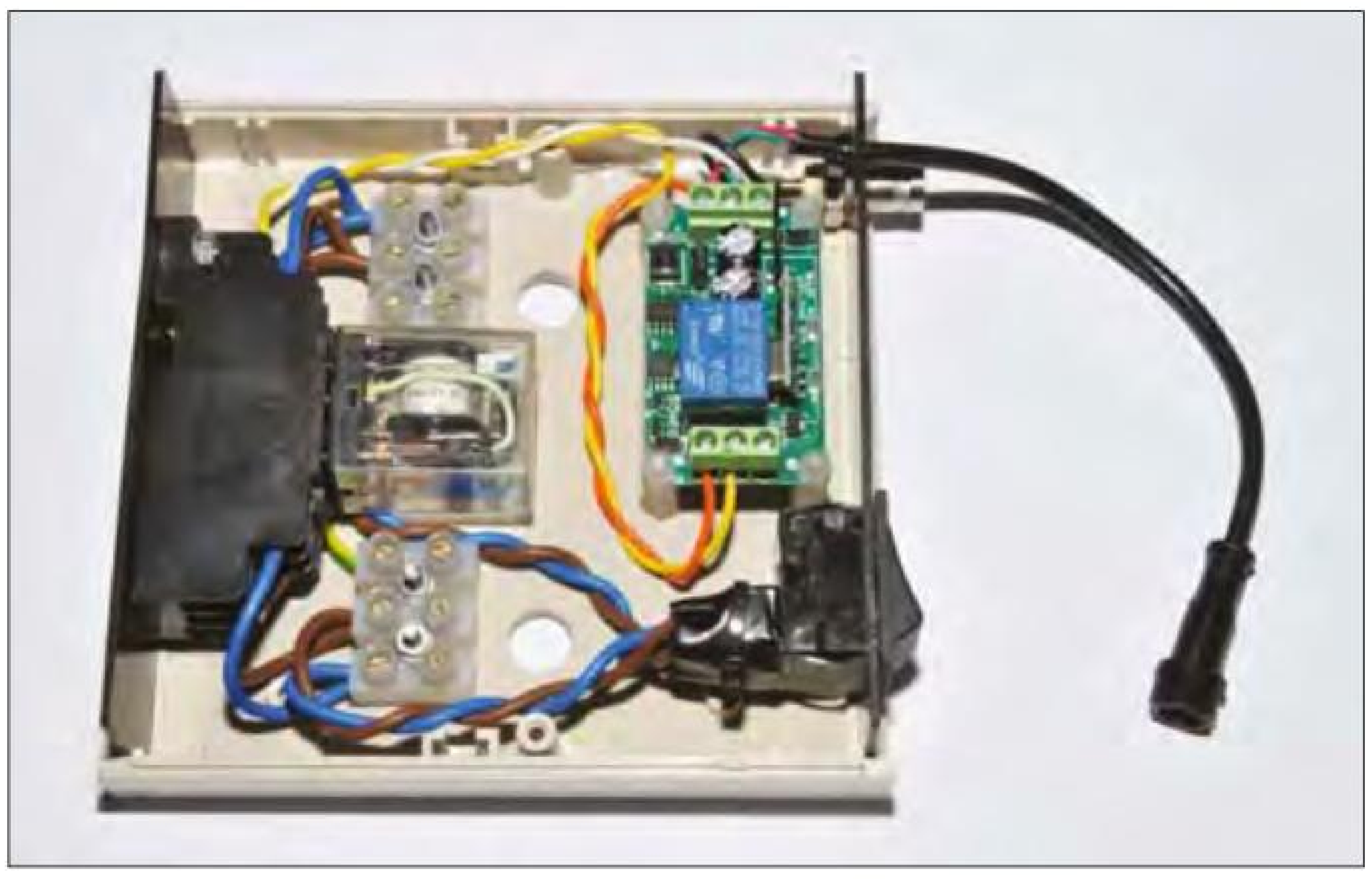


Fig.2. The long-distance remote control uses a low-cost receiver module, a mains-power relay – and not much else. Also fitted here is a manual override switch and connections for power and an external antenna. The power cable uses a pre-wired plug-and-socket combination (the socket is shown here).

Remote control receiver and transmitter

While most remote-control modules have a quite limited range, there are others available that are much better in this respect. Typically, these are dubbed 'long range' or 'long distance'. The one I bought on eBay was called 'Garage Door Long-Distance DC12V/24V RF Wireless Remote Control Switch System12V 433MHz'. It cost £14 delivered. Do also check Amazon.

Frustratingly, at the time of writing this, I cannot find an identical unit for sale, so here are some hints in making your selection.

First, the unit should be sold specifically as a long-range remote control. (But take with a large grain of salt the stated operating distances – some units that appear to be identical have quoted maximum distances that vary from 300m to 1000m.) Second, the transmitter should have an extendable antenna and be quite a lot larger than the typical 'key fob' style of remote control.

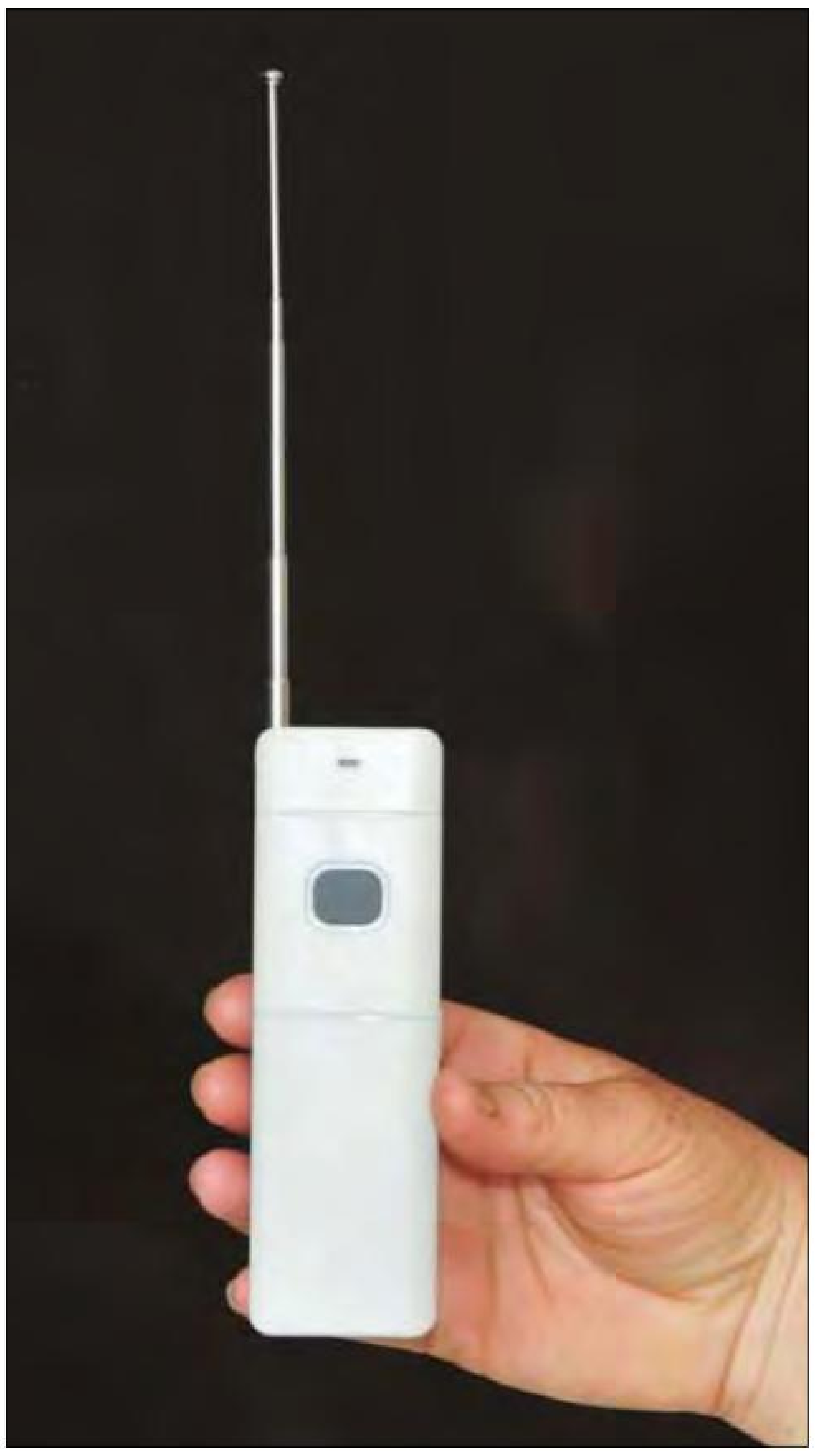


Fig.3. When selecting a suitable long-range remote-control module and transmitter, ensure the transmitter is larger than a typical 'key fob' style remote and has an extendable antenna.

The receiver also needs to have a relay output, and you should be able to configure it to have a latching function – that is, one press of the remote turns the relay on, and another press turns it off. Finally, pick an operating voltage that, preferably, suits a surplus plug-pack ('wall wart') that you may have in your spare parts drawer.

Note that I used a single-channel remote control system, but multi-channel systems are a similar price, so think about whether having multiple channels (now or in the future) might be useful.

Other parts

The other main part that you will need is a mains power relay that's rated for the current you are switching. In my case, I am operating two 300W lamps, with a third to be potentially added in the future. With my local (measured) 240V supply voltage, that's a little under 4A total. I selected a 5A (at 250V) relay from my parts box – it turned out to be a double-pole, double-throw (DPDT) design.

Relays with mains-voltage ratings up to 10A are quite common; above that you may need to go for a mains power 'contactor' of the sort often used when turning on and off heavy electrical machinery. Don't forget to select a relay that uses a coil voltage that matches the remote-control receiver's operating voltage – in my case, 12V.

Many relays aren't designed to accept screw or similar terminals. An easy way to overcome this problem is to select a relay that plugs into a screw terminal base. The base also typically has holes for mounting, allowing both easy wiring connections to the relay and for it to be securely mounted.

You will also need an enclosure to allow the parts to be mounted and kept away from inquisitive fingers. But rather than go through each minor part one by one, let's look instead at how the system was assembled.

Building it

The box I used was a good-quality plastic enclosure about 130 x 130 x 40mm. A clamshell design, it had two removable plastic end panels. On the inside of one end panel I mounted the 5A relay and its plug-in base. Since it was a DPDT unit, I decided to switch both the live and neutral connections.

On the other end panel I mounted a mains-rated 10A switch. This switch is optional. I fitted it so that the lights could still be manually operated if the remote control were to fail (eg, the transmitter was temporarily mislaid, had a flat battery or simply broke). I used a double-pole single-throw (DPST) switch so that again I could switch both live and neutral feeds.

Two holes were also drilled in this end panel. One was for the power supply cable from the plugpack and the other for a BNC antenna socket (more on this socket in a moment).

On the floor of the enclosure I mounted, using plastic stand-offs, the remote-control receiver. Also mounted on the floor of the enclosure were two three-terminal connecting blocks – one for the mains inlet and the other for the outlet to the lights. Adjacent to these terminal blocks, holes were drilled to admit these cables. The holes were placed in the bottom of the box because the box was to be mounted flush against the power board panel within the meter box – these cables come through this mounting panel.

The standard receiver antenna for this module (and most others) is a short length of coiled wire. Impressively, I tested the remote module with this standard antenna and found it worked at up to 100m range – even with the receiver inside the metal meter box. However, obviously such RF shielding is not ideal and so I added the antenna socket to allow an external antenna to be fitted. The shield wire of the socket is connected to the negative power terminal of the board (when accessing the receiver connections is near impossible, it's a little hard to work out the best approach). The coiled antenna was cut off short and the remaining end of this wire soldered to the centre pin of the BNC socket.

The antenna itself consists of a 270mm long piece of stainless-steel wire. I

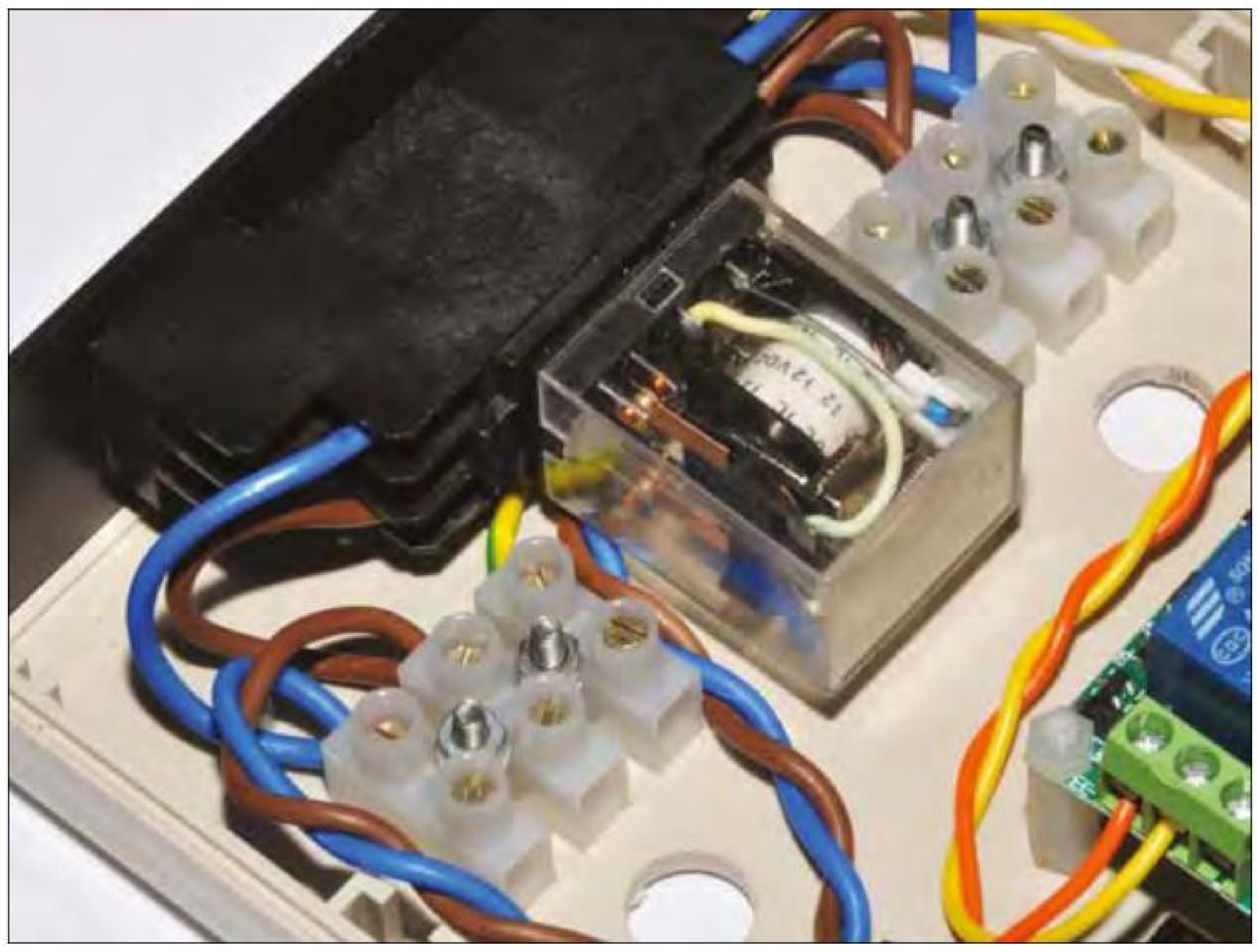


Fig.4. This shows the terminal blocks for the mains power in/out connections and associated cable entrance holes. These terminal blocks make connections in the field quite easy.

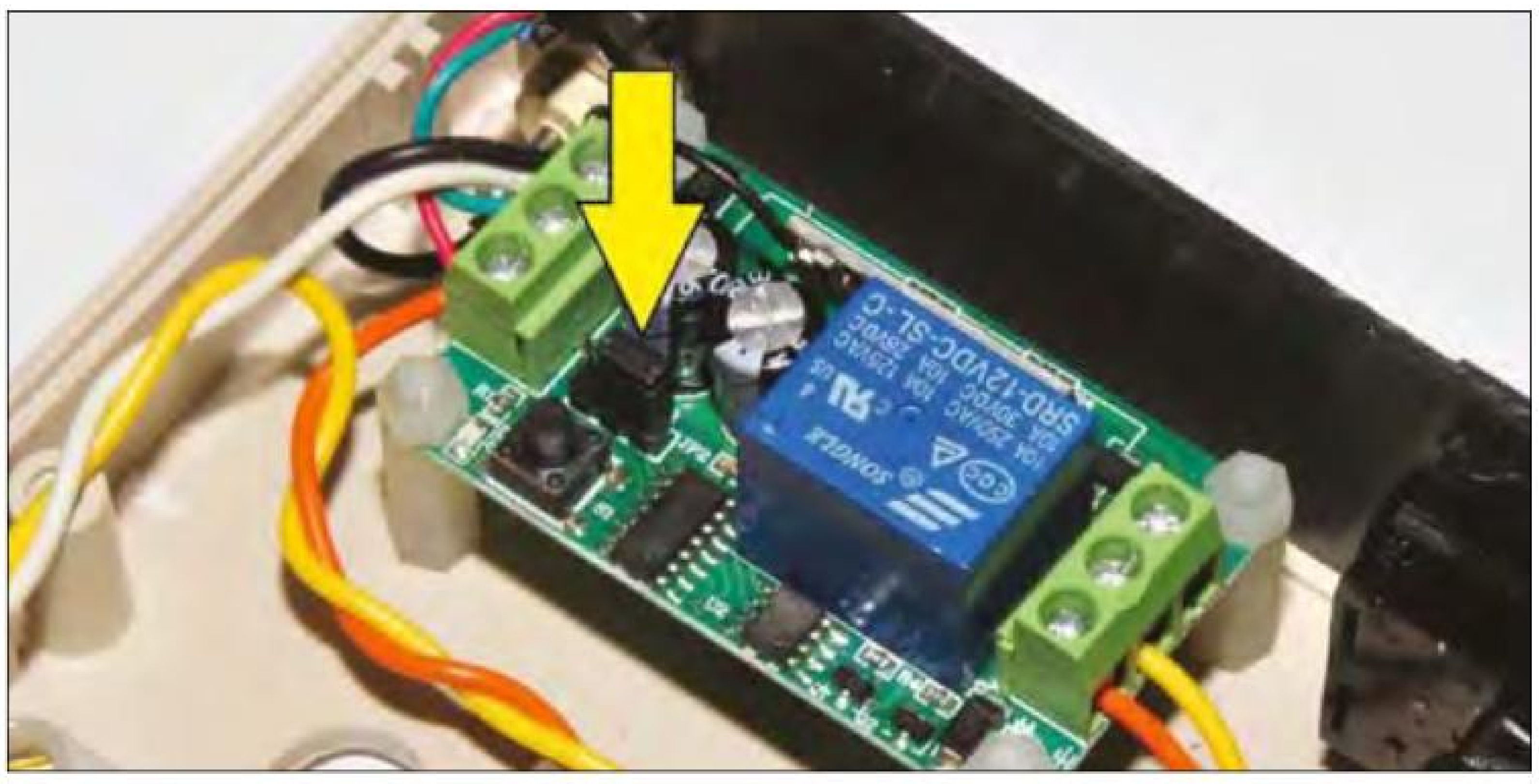


Fig.5. This remote-control module has a configurable link (arrowed). With the link in one position the relay engages when the remote-control button is pressed; in the other position the relay latches with one button press and unlatches with the next press. For applications like mine you want the latter system. The PCB button adjacent to the link is a 'learning' button, allowing the system to be used with multiple remotes. On the far right is the manual override switch that directly switches the mains power to the outlet. Note that its terminals have been insulated – no mains wiring should be exposed.

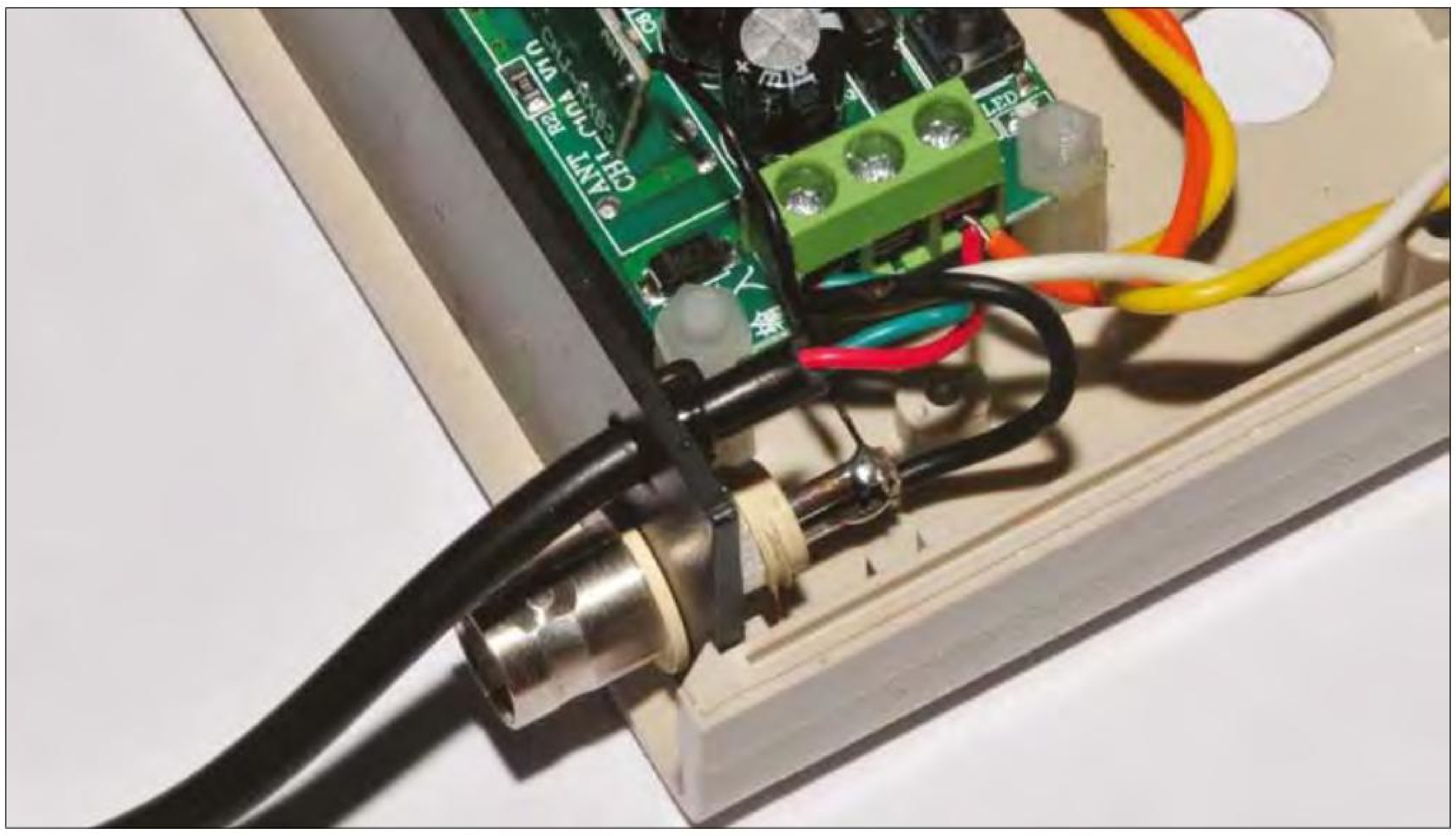


Fig.6. Here you can see the power cable (top) and BNC antenna connection (bottom). It's a little hard to see, but the original 'coiled wire' antenna has been cut short and soldered to the centre pin of the BNC connector. Since this receiver is to be mounted in a metal box, an external antenna adds noticeable range.

used TIG welding wire, but a stainless-steel bicycle wheel spoke could also be used. Using pliers, one end of the wire was wound around a suitable diameter mandrel (a long screw held in a bench vice) and then a right-angle bend placed in the wire. This approach allowed the antenna to be easily attached by a screw and washers to a threaded porcelain insulator. (The insulator came from parts I inherited from my father, so it's perhaps 70 or 80 years old – it gives me a good feeling to re-use old bits and pieces) Connection to the antenna is via an eye terminal that fits under the antenna mounting screw. I used a short length of 50Ω coaxial cable to connect the antenna to the BNC connector.

If you wished, it would be easy to trial different antenna lengths and connection methods. Simply power-up the receiver module, position an assistant with a mobile phone so that they can see the module, and then try triggering it from greater and greater distances while staying in phone contact with the assistant. I did exactly that and found that with the described antenna, I could achieve reliable operation at over 300m range – and that was with the receiver located inside a house, and with a large steel shed blocking line of sight.

After that it was just a case of installing the receiver module in the mains power meter box and making the connections.

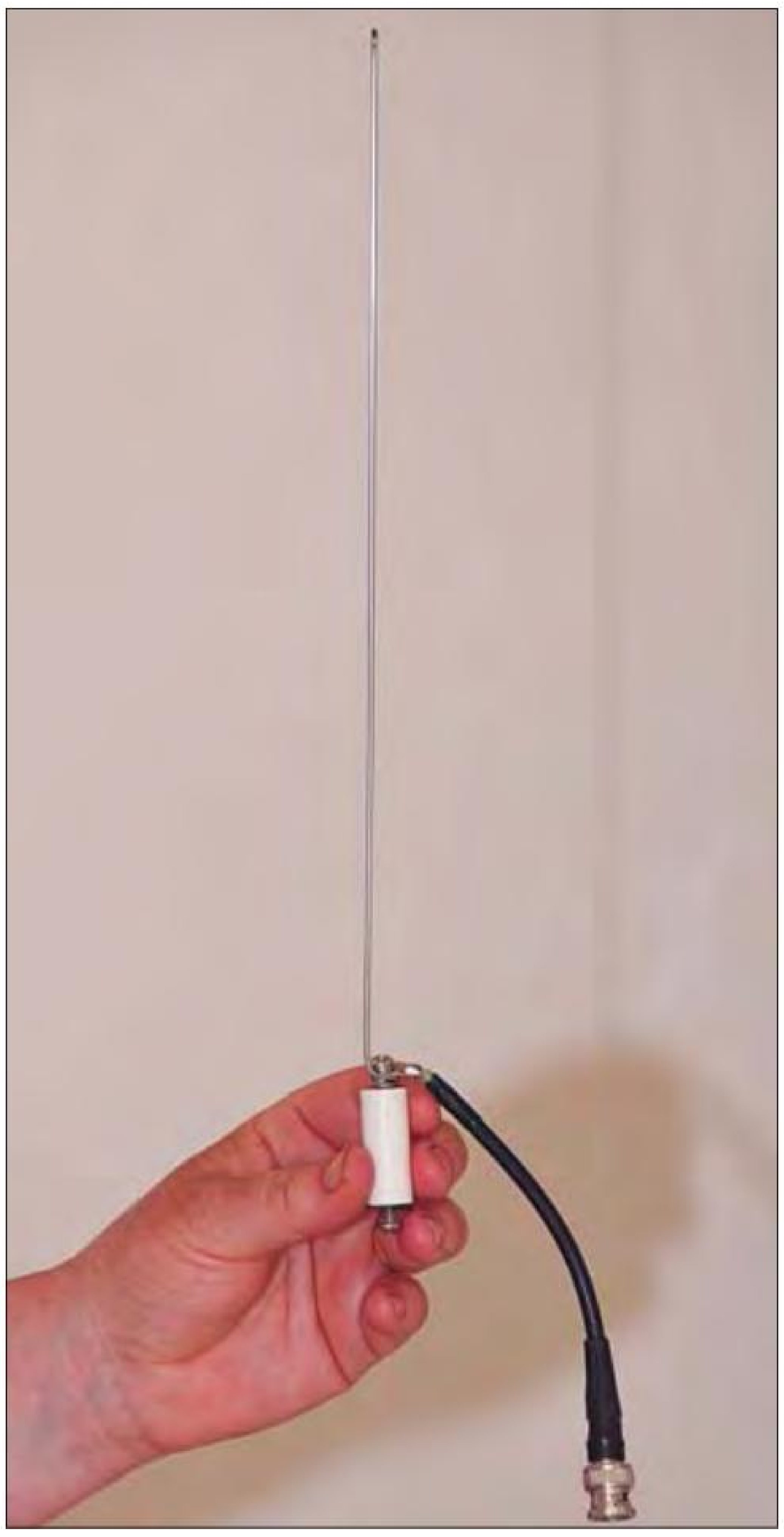


Fig.7. The new external antenna was made from a short length of stainless-steel wire mounted to a porcelain insulator.

Outcome

It's not a complex project or even one that takes much time to assemble. But it works well. It didn't cost a great deal but achieved the outcome I wanted. And isn't that what we want with our electronics projects?

The two 300W entrance lights. They light-up literally thousands of square metres – and with the remote control, they can be switched from up to 100m away.

You may be wondering at the power rating of these lights – 300W each!? Hasn't his guy heard of LED lights? What must it cost to run these!

Well, it's an interesting story – and worth a brief excursion.The lighting units shown above are high-quality commercial metal-halide lights, as used in large parks and gardens. They are made with cast alloy housings and polished stainless-steel reflectors – disassembled, you can see their quality throughout.

Once, they would have been worth perhaps £200 each – but we got them from the shop at the local rubbish tip (recycling centre) for just £5 each. And they were brand new! Obviously, a local government authority swapped all their new parkland lights to LEDs and decided these lights were worthless.

Of course, metal halide lights will use a lot more energy than LEDs to run, but when they'll be on only occasionally (and usually for short periods), the total cost will be fine – especially considering the immense amount of light they produce.

Practical Electronics PCB SERVICE

PROJECT	CODE	PRICE
NOVEMBER 2023		
LC Meter Mk3	CSE220503C	9.95
DC Supply Filter for vehicles	08108221	8.95
Discrete Audio Op Amp PCB	AO1-JUL23	9.95
Discrete Audio Op Amp PCB + essential components	AO2-JUL23	17.95
OCTOBER 2023		
Buck/Boost Charger Adaptor	14108221	9.95
PIC Breakout Board for SOIC parts	24110225	5.95
PIC Breakout Board for DIP parts	24110222	5.95
AVR64DD32 Breakout board	24110223	5.95
Automatic Train Controller	09109221	6.95
Chuff Sound module	09109222	6.95
SEPTEMBER 2023		
Mini LED Driver	16106221	7.95
New GPS-Synchronised Clock	19109221	9.95
Wide-Range Ohmmeter	04109221	14.95
AUGUST 2023		
110dB RF Attenuator	CSE211003	9.95
Universal Battery Charge Controller (2023 update)	14107192	9.95
Wide-Range OhmMeter	04109221	12.95
JULY 2023		
Multimeter Checker/Calibrator	04107221	10.95
MIDI Spectral Sound Synthesiser (full kit – see p.25)	N/A	N/A
JUNE 2023		
Arduino Programmable Load	04105221	8.95
Buck-Boost LED Driver	16103221	8.95
MAY 2023		
Precision AM-FM DDS Signal Generator	CSE211002	14.95
Improved SMD Test Tweezers programmed PIC	0410621PIC	12.95
AO 2x-dual-to-quad through-hole (pack of five)	AO1-MAY23	6.95
AO 2x-dual-to-quad SMD (pack of five)	AO2-MAY23	6.95
AO 2x-single-to-dual through-hole (pack of five)	AO3-MAY23	6.95
AO 2x-single-to-dual SMD (pack of five)	AO4-MAY23	6.95
APRIL 2023		
500W Amplifier Module	see p.22, April 2023	
Clipping Indicator (per channel)	01112211	7.95
CD Welder Power Supply (one needed)	29103221	9.95
CD Welder Controller (one needed)	29103222	9.95
CD Welder Energy Storage module (several needed)	29103223	7.95
AO Universal Dual Op Amp Board	AO1-APR23	9.95
AO Stereo RIAA precision passives kit for dual op amp	AO2-APR23	8.95
MARCH 2023		
Pico BackPack	07101221	9.95
Semaphore Signal (controller)	09103221	7.95
Semaphore Signal (blade)	09103222	5.95
FEBRUARY 2023		
Tesla Coil driver board	26102221	9.95
Tesla Coil potentiometer board	26102222	5.95
Cooling Fan Controller & Loudspeaker Protector	01102221	8.95
Remote Gate Controller	11009121	12.95

PROJECT	CODE	PRICE
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Classic LED Metronome – 8-LED	23111211	7.95
Classic LED Metronome – 10-LED	23111212	8.95
Multi-Channel Speaker Protector – 6 channel	01101221	9.95
Multi-Channel Speaker Protector – 4 channel	01101222	7.95
Remote Control Range Extender – IR-to-UHF	15109212	5.95
Remote Control Range Extender – UHF-to-IR	15109211	7.95
AO Universal Single Op Amp Board	AO1-JAN23	7.95
DECEMBER 2022		
Hummingbird Amplifier	01111211	9.95
SMD Trainer PCB	29106211A	8.95
SMD Trainer PCB + parts	29106211B	13.95
NOVEMBER 2022		
USB Cable tester – main PCB	04108211	12.95
USB Cable tester – front panel	04108212	5.95
USB Cable tester – optional panel	SC5970	5.95
Model Railway Carriage Lights – PCB	09109211	6.95
AO transfmr PCB – standard VTX-A range	VTX-101-007	6.95
AO transfmr PCB – dual-outline VTX102-3001/101-3002	VTX-Dual	6.95
OCTOBER 2022		
SMD Test Tweezers – PCB and pair of tweezer arms	04106211-2	11.95
SMD Test Tweezers – programmed PIC12F1572-I/SN	0410621A	7.95
Tele-com	12110211	12.95
SEPTEMBER 2022		
Touchscreen Digital Preamp – main board	01103191	12.95
Touchscreen Digital Preamp – adaptor board pair	01103192	5.95
20A DC Motor Speed Controller	11006211	9.95
AUGUST 2022		
Multi-purpose Battery Manager – I/O Expander module	11104212	5.95
Multi-purpose Battery Manager – Switch Module	11104211	8.95
Simple MIDI Music Keyboard (for 8 switches)	23101213	6.95
Nano Pong	08105212	7.95
JULY 2022		
Silicon Labs AM/FM/SW Radio	CSE210301C	10.95
Level Crossing Controller	09108211	6.95
JUNE 2022		
Full-wave Motor Speed Controller	1010221	8.95
PIC Programming Helper for 8-pin PICs only	24106211	7.95
PIC Programming Helper for 8, 14 or 20-pin PICs	24106212	10.95
Advanced GPS Computer	05102211	9.95
MAY 2022		
Bus board PCB for Analogue Vocoder	AO1-MAY22	10.95
Complete set of 14 PCBs for Analogue Vocoder	AO2-MAY22	97.95
Programmed EEPROM for Digital FX Unit	FX1-MAY22	10.95
Programmed PIC for Digital FX Unit using potentiometer	FX2-MAY22	8.95
APRIL 2022		
64-key MIDI Matrix shield	23101211	8.95
64-key MIDI Matrix switch board	23101212	11.95
High-current Battery Balancer	14102211	10.95
Digital FX Unit – using potentiometer	01102211	9.95
Digital FX Unit – using BCD switch	01102212	9.95
Universal Audio PSU	AO1-APR22	11.95
MARCH 2022		
Mini Isolated Serial Link	24102211	£5.95
Busy Loo Indicator	16112201	£5.95
Analogue Vocoder – Band-pass filter board	AO1-MAR22	9.95
Analogue Vocoder – HP/LP filter board	AO2-MAR22	9.95

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

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FEBRUARY 2022		
Arduino-based Power Supply	18106201	9.95
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Electronic Wind Chimes	23011201	10.95
Analogue Vocoder – Driver Amplifier	AO-FEB22	8.95
JANUARY 2022		
Vintage battery Radio Li-ion Power Supply	11111201	9.95
MiniHeart: A Miniature Heartbeat Simulator	01109201	8.95
DECEMBER 2021		
AM/FM/SW Digital Receiver	CSE200902A	13.95
Balanced Input and Attenuator for USB CODEC	01106202	11.95
NOVEMBER 2021		
Dual Battery Lifesaver	11111202	£6.95
OCTOBER 2021		
Mini Wi-Fi LCD BackPack	24106201	£8.95
SEPTEMBER 2021		
USB SuperCodec PCB	01106201	£14.95
Audio DDS Oscillator PCB	01110201	£5.95
Audio DDS Oscillator rotary encoder	01110201-ENC	6.95
Programming Adaptor Board for Audio DDS Oscillator	01110202	£5.95
High-power Ultrasonic Cleaner main PCB	04105201	£14.95
High-power Ultrasonic Cleaner front-panel PCB	04105202	
Night Keeper Lighthouse PCB	08110201	£5.95
AUGUST 2021		
Ol' Timer PCB	19104201	£11.95
Ol' Timer 8x8 RGB LED module using WS2812B	19104201-88	£8.95
Ol' Timer set of acrylic case pieces and spacer	19104201-ACR	£8.75
Ol' Timer DS3231 RTC IC wide SOIC-16	19104201-RTC	£5.95
Wideband Digital RF Power Meter	04106201	£9.75
Switchmode 78xx regulators ***(PACK of 5!)***	18105201	£7.95
Cool Beans SMAD display	CB-AUG21	£11.95
JULY 2021		
ATtiny816 Breakout / Dev Board with Capacitive Touch	24110181	£9.75
IR Remote Control Assistant (Jaycar version)	15005201	£8.95
IR Remote Control Assistant (Altronics version)	15005202	£8.95
PIC18F Development Board	PNM-JUL21	£12.95
Microphone Preamplifier	AO-JUL21	£11.95
JUNE 2021		
Roadies' Test Signal Generator (surface-mount version)	01005201	£8.95
Roadies' Test Signal Generator (through-hole version)	01005202	£9.95
Touchscreen Wide-range RCL Box (Resistor module)	04104201	£18.95
Touchscreen Wide-range RCL Box (Ind/Cap module)	04104202	
KickStart Part 3 – Gyrator-based Audio Filter	KS3-2021	£7.95
MAY 2021		
7-Band Equaliser (Mono)	01104201	£8.95
7-Band Equaliser (Stereo)	01104202	£10.95
Car Altimeter	05105201	£7.95
APRIL 2021		
Reflow Oven – DSP Active Crossover (CPU)	01106193	£19.95
Reflow Oven – DSP Active Crossover (Front panel)	01106195	
Reflow Oven – DSP Active Crossover (LCD)	01106196	
Frequency Reference Signal Distributor	CSE200103	£8.95
MARCH 2021		
Nutube Guitar Effects Pedal	01102201	£12.95
Programmable Thermal Regulator (Peltier Interface)	21109181	£18.95
Programmable Thermal Regulator (Peltier Driver)	21109182	
Tunable HF Preamp	CSE190502	£8.95
FEBRUARY 2021		
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DECEMBER 2020		
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LED Christmas Tree (20 off)	16107181-4	£34.95
USB/SPI Interface Board	16107182	£5.95
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45V/8A Power Supply front panel five-way display bezel	18111181-BZ	£3.95
Five-way LCD Panel Meter/Display	18111182	£7.95
OCTOBER 2020		
Digital Audio Millivoltmeter	04108191	£9.95
Precision Signal Amplifier	04107191	£7.95
SEPTEMBER 2020		
PE Theremin PSU	AO-0920-01	£5.95
PE Theremin PSU transformer	AO-0920-02	£7.95
Micromite Explore-28	07108191	£6.95
Ultrabrite LED Driver	16109191	£6.95
AUGUST 2020		
Micromite LCD BackPack V3	07106191	£9.95
Steering Wheel Audio Button to Infrared Adaptor	05105191	£7.95
JULY 2020		
AM/FM/CW Scanning HF/VHF RF Signal Generator	04106191	£13.95
Speech Synthesiser with the Raspberry Pi Zero	01106191	£5.95
PE Mini-organ PCB	AO-0720-01	£14.95
PE Mini-organ selected parts	AO-0720-02	£8.95
High-current Solid-state 12V Battery Isolator – control	05106191	£6.95
High-current Solid-state 12V Battery Isolator FET (2oz)	05106192	£9.95
JUNE 2020		
Arduino breakout board – 3.5-inch LCD Display	24111181	£6.95
Six-input Audio Selector main board	01110191	£10.95
Six-input Audio Selector switch panel board	01110192	
MAY 2020		
Ultra-low-distortion Preamplifier Input Selector	01111112	£11.25
Ultra-low-distortion Preamplifier pushbutton Input Selector	01111113	
Universal Regulator	18103111	£7.95
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Bridge-mode Adaptor for Amplifier	01105191	£7.95
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Analogue noise with tilt control	AO-0520-01	£7.95
Audio Spectrum Analyser	PM-0520-01	£8.95
APRIL 2020		
Flip-dot Display black coil board	19111181	£14.95
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Flip-dot Display green driver board	19111184	
MARCH 2020		
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DECEMBER 2019		
Extremely Sensitive Magnetometer	04101011	£16.75
Four-channel High-current DC Fan and Pump Controller	05108181	£8.75
Useless Box	08111181	£11.50
NOVEMBER 2019		
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Tinnitus & Insomnia Killer (Altronics case – see text)	01110182	£9.95
OCTOBER 2019		
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Digital Command Control Programmer for Decoders	09107181	£9.95
Opto-isolated Mains Relay (main board)	10107181	£11.50
Opto-isolated Mains Relay (2 × terminal extension board)	10107182	
AUGUST 2019		
Brainwave Monitor	25108181	£12.90
Super Digital Sound Effects Module	01107181	£6.95
Watchdog Alarm	03107181	£8.00
PE Theremin (three boards: pitch, volume, VCA)	PETX0819	£19.50
PE Theremin component pack (see p.56, August 2019)	PETY0819	£15.00
JULY 2019		
Full-wave 10A Universal Motor Speed Controller	10102181	£12.90
Recurring Event Reminder	19107181	£8.00
Temperature Switch Mk2	05105181	£10.45
JUNE 2019		
Arduino-based LC Meter	04106181	£8.00
USB Flexitimer	19106181	£10.45
MAY 2019		
2× 12V Battery Balancer	14106181	£5.95
Deluxe Frequency Switch	05104181	£10.45
USB Port Protector	07105181	£5.95
APRIL 2019		
Heater Controller	10104181	£14.00
MARCH 2019		
10-LED Bargraph Main Board	04101181	£11.25
+Processing Board	04101182	£8.60
FEBRUARY 2019		
1.5kW Induction Motor Speed Controller	10105122	£24.95
NOVEMBER 2018		
Super-7 AM Radio Receiver	06111171	£15.95
OCTOBER 2018		
6GHz+ Touchscreen Frequency Counter	04110171	£12.95
Two 230VAC MainsTimers	10108161	£11.95
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SEPTEMBER 2018		
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AUGUST 2018		
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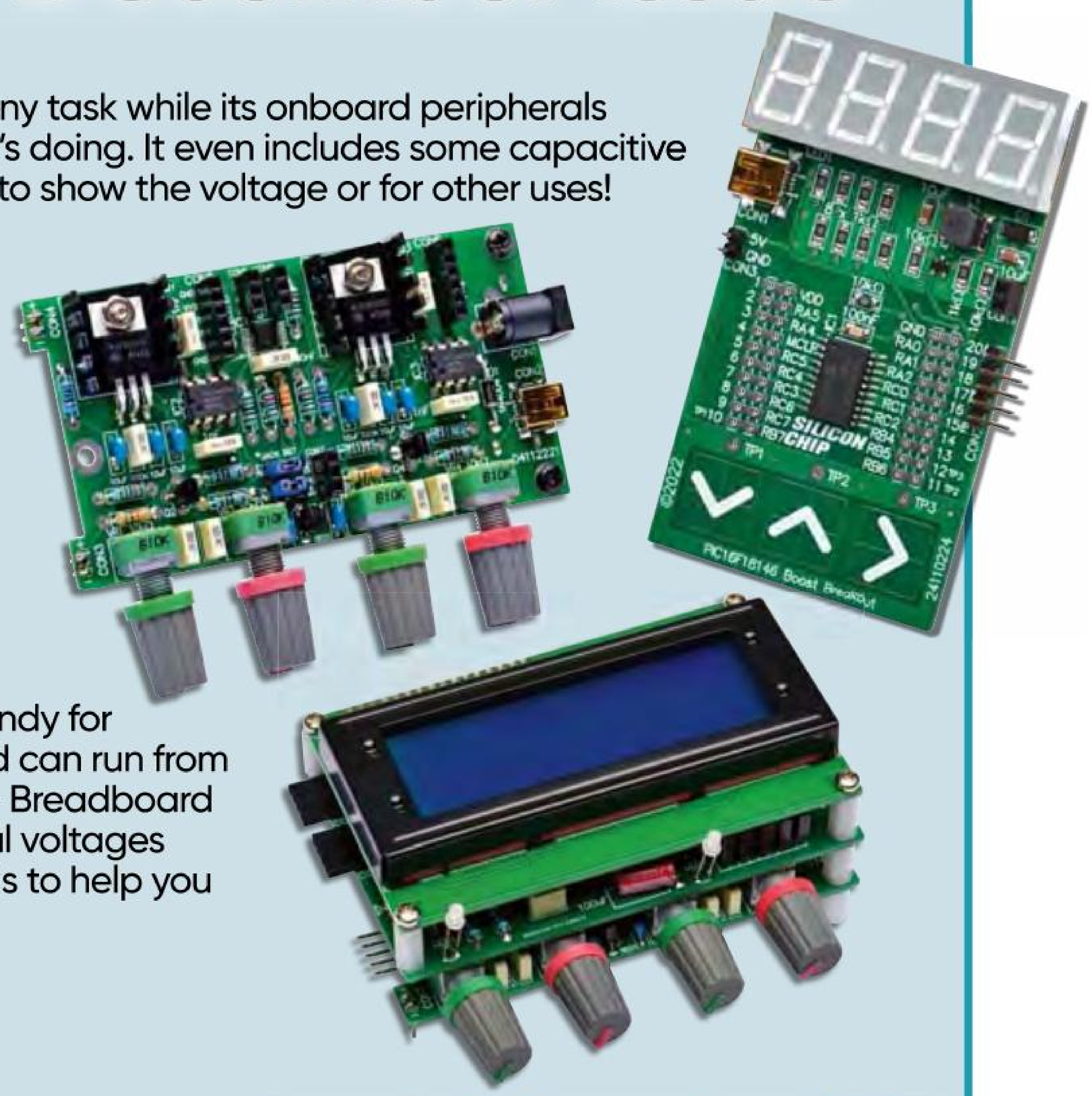
Next Month – in the December issue



Digital Boost Regulator

This board lets you use a PIC18F18146 8-bit microcontroller for any task while its onboard peripherals generate an adjustable voltage without interfering with what it's doing. It even includes some capacitive sense buttons and a seven-segment display that can be used to show the voltage or for other uses!

Dual-Channel Power Supply for Breadboards

Things can get messy when you're prototyping a design on a breadboard – but you don't want to make a mistake hooking up the power supply! This Dual-Channel Breadboard PSU is the perfect solution. It plugs straight into a breadboard's power rails, has two adjustable current-limited outputs and can run from different power sources. It has already become an indispensable part of our workbench.

Display Adaptor for the Breadboard PSU

The Dual Channel Breadboard PSU (above) is compact and handy for prototyping. It slots straight into a breadboard's power rails and can run from a plugpack or USB supply. The Display Adaptor attaches to the Breadboard PSU and displays lots of handy data, such as the set and actual voltages and currents. It even has extra voltmeter and ammeter channels to help you analyse your prototype!

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Source
Drain
N-Ch Enhancement mode MOSFET
D
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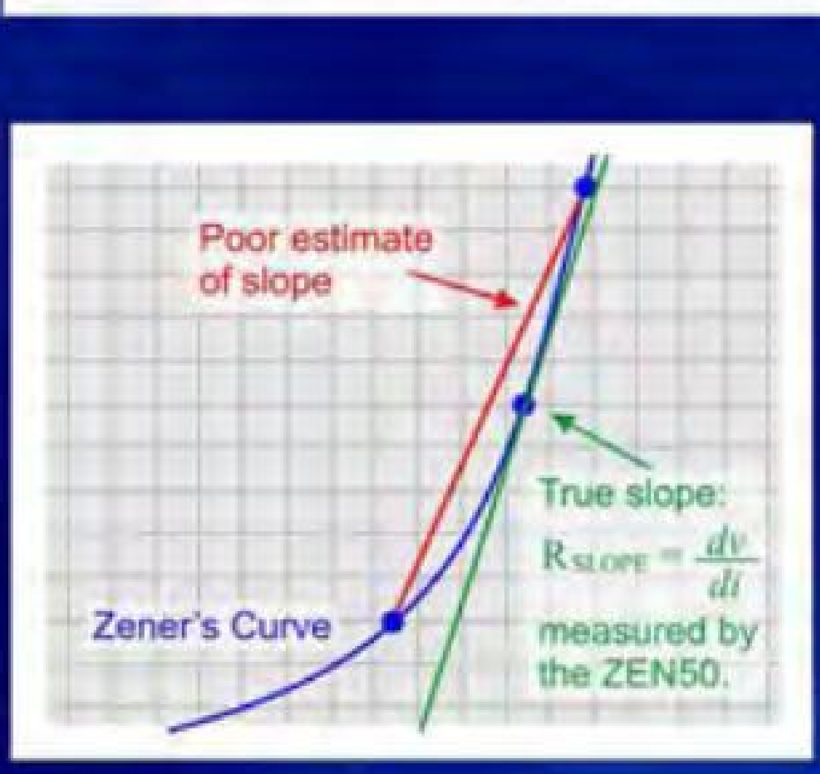

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